VERTIGO

(Vestibular Enhancement & Rehabilitation Therapy for Interactive Growth & Optimization)

Prepared for: Dr. Raelene Hardy, Shirley Ryan Abilitylab Homewood

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Executive Summary

Problem

Our client, Dr. Raelene Hardy from SRAL Homewood, treats patients with vestibular dysfunction who suffer from symptoms like balance issues, dizziness, and weak eye muscles. Current therapy methods using sticky notes and meter sticks are improvised and lack diversity and engagement. We are tasked with designing a dual-tasking device to streamline and enhance therapy sessions, providing Dr. Hardy with a more effective tool for her patients.

Requirements

The device must offer task diversity by providing multiple designs for testing visual tracking and dual-tasking. It should be easily customizable with different weights and inserts to tailor therapy sessions to individual patient needs. Additionally, the device must be user-friendly with minimal preparation time and durable enough to withstand frequent use, falls, and scratches.

Methodology

We conducted initial research and held meetings with Dr. Hardy to gather requirements. Our design process included creating 3D models, developing prototypes, and iterating based on feedback from Dr. Hardy and user observations. We selected durable materials and tested the device for usability, ensuring it met all specified requirements.

Design

The VERTIGO device is a 36-inch clear plastic tube that enhances vestibular rehabilitation therapy. It includes magnetic end caps, removable steel rods for adjustable weight, and customizable inserts with various engravings like alphabets and numbers. The device can also incorporate a marble for added tactile engagement, making exercises more interactive and diverse for patients.

Introduction

Vestibular dysfunction is a disturbance in the body's balance system that induces problems with hearing, vision and balance, along with dizziness or nausea. The main form of treatment is through rehabilitation therapy, which includes balance training, visual tracking exercises both smooth and rapid, stretching and strengthening. Our project partner, Dr Raelene Hardy works with patients with vestibular deficit in the Shirley Ryan AbilityLab located in Homewood, Illinois. Her approach with vestibular rehabilitation therapy is to help patients through dual-tasking exercises, in which they must hold an object, commonly a meter stick, while their gaze follows sticky notes that she will move from side to side, or up and down. This gaze shifting is done in two methods: smooth visual tracking & saccades. Smooth visual tracking is done in a slow continuous motion. Saccades include discontinuous, rapid eye movements, between targets often a few inches apart. The goal of visual tracking is to provoke dizziness in a controlled environment, to promote resistance of symptoms in real world scenarios. Therapy is also done in groups, where patients will take turns engaging in the dual-tasking exercises.

Dr. Hardy is limited in her options when it comes to setting up dual-tasking exercises for patients, with her ingenuity driving her methods. The meter stick and sticky notes exercise was something she came up with, for example. Additionally, she has to use a lot of time in setup given the short hour-long sessions, for example with exercises that require her taping sticky notes to corners of the room. After multiple sessions of vestibular therapy, the exercises can become repetitive and boring both for Dr. Hardy and the patients.

The Vestibular Enhancement & Rehabilitation Therapy for Interactive Growth & Optimization (VERTIGO) is a 36 inch long clear plastic tube that will help Dr Hardy with vestibular rehabilitation therapy, specifically, she will use the device by giving it to patients to hold, testing smooth visual tracking & saccades with visual cues housed within the device, and strength through use of adjustable weight. It consists of two plastic end caps that attach by magnet to brackets, which are plastic pieces permanently attached to the inside of the tube. The other function of the brackets is to stabilize the removable steel rod used for adjustable weight, and house the inserts. The inserts are thin wooden boards that have different engravings, such as the alphabet, numbers 1-10, colors, etc. There is also the option to include a marble within the tube, and running it along a track engraved onto an insert. The inserts are what take the role of the exchangeable visual stimuli, presently the sticky notes that Dr. Hardy places around the treatment area, or on a meter stick.
The device is cylindrical and clear, which is easier for patients to grasp than other rigid shapes, and allows for the inserts within to be seen. The device can also be easily cleaned, in regards to how commonly it will be used during therapy sessions.

This report will explain the users and project requirements, the limitations and future directions given more resources, followed by an explanation of the design and its rationale.

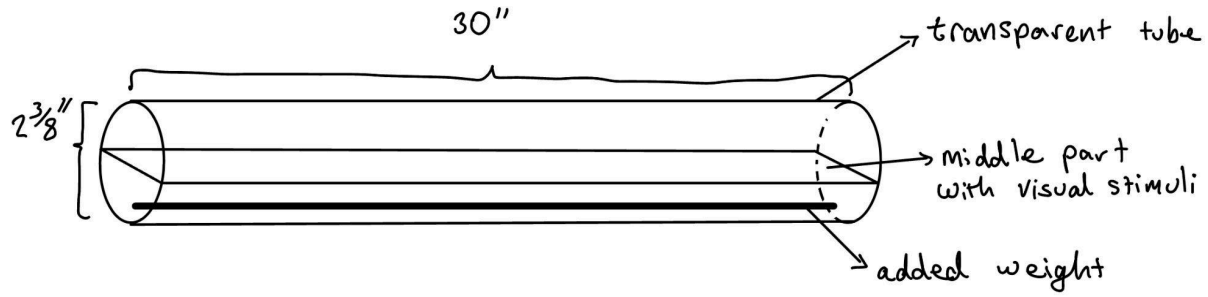
Users and Major Requirements

Our client is Dr. Hardy, a physical therapist at SRALab Homewood DayRehab Center. The primary users of this device will be the patients experiencing vestibular disorders, often caused by medications, infections, inner ear problems, or traumatic brain injury. These patients are mostly middle-aged with a range of vestibular symptoms, including: difficulty with balance, dizziness, headaches, difficulties with hand-eye coordination, and weakened eye muscles. Dr Hardy utilizes Vestibular Rehabilitation Therapy (VRT) in her treatment process to manage symptoms through exercises aimed at improving balance and vision stability. Currently, our client uses sticky notes for head and eye movement exercises, which are effective but inefficient for therapeutic purposes. The main requirements Dr Hardy wanted in our product are task diversity, customizability, and durability. Our product can be used in sitting, standing, and walking positions while providing visual stimuli and exercising hand eye coordination. This provides freedom in which the product can be utilized by Dr Hardy. The customizability aspect is reinforced by the interchangeable wooden parts which can have any kind of visual stimuli for each user. In addition, we have selected PVC pipe for the tube, 3D printed PLA end caps, and epoxy glue for most durability against impact and aging.

Design Concept and Rationale

Our design concept is essentially composed of 3 sections (upper, middle and lower) inside a transparent PVC pipe. Middle part provides customizable visual stimuli to the patients. This part will be made of interchangeable wooden plates with various colors, images, letters, words, numbers, ect. This section will be utilized in therapy sessions for eye and neck movement exercises. The upper section will be used for tactile stimuli such as a marble maze that the patients will try to solve by tilting the PVC pipe. The marble maze will combine visual and tactile stimuli for patients' to exercise their multi-tasking. The lower section is used for adding weights for different therapy exercises. The increased weights will help train the paients' body strength. The transparent pipe will have end caps on both sides, one glued shut and the other connected via magnets. The magnet-connected end will be able to be opened by Dr Hardy to customize the product for each and every patient's needs.

Image 1: Sketch of the Design



Limitations and Direction for Future Development

Limitations:

- Fragile materials
    - We conducted very little testing on our product, including drop tests, due to time constraints. We do not know for sure how well our product will hold up if it suffers repeated impact
- Ability to add features
    - While our inserts are well-thought-out and built under the guidance of Dr Hardy, she may eventually desire more designs, and the inserts are not easily made without Northwestern's resources

Future Developments:

- Weight Customizability
    - Further enhance the customizability of the product by introducing a broader range of weights with varying classes. This will allow our client to tailor therapy sessions more precisely to individual needs and capabilities of each patient, thereby providing a more personalized and effective treatment experience.

- End Caps
    - Creating stronger and more secure end caps to ensure that weight and insert are secured firmly.

- Designs
    - Create more designs that expand the range of designs available, incorporating more tasks that test and improve various aspects of vestibular therapy - such as saccades and smooth pursuit. Furthermore, we aim to create inserts that can be easily customized within the therapy space, which will allow therapists to adapt the device quickly and create a range of designs catering to patients.

Conclusion

The development of VERTIGO has been a thorough and collaborative effort to address the specific needs of Dr. Raelene Hardy and her patients at the Shirley Ryan AbilityLab Homewood, Illinois. Through research, iterative design, and collaboration with our project partner, we have created a versatile tool for vestibular rehabilitation therapy.

VERTIGO meets the key requirements of task diversity, customizability, ease of use, and durability. It provides a range of exercises to engage patients in visual tracking and dual-tasking, essential for improving balance and vision stability. The interchangeable inserts and adjustable weight allow personalized therapy sessions tailored to each patient's needs. The user-friendly design ensures minimal setup time, and the robust materials guarantee durability for frequent clinical use.

Our methodology included multiple development stages, from initial concept and prototyping to user feedback and final validation. This structured approach ensured the final product was refined and optimized based on real-world observations and expert input. Insights from therapy sessions and consultations with Dr. Hardy were crucial in shaping the final design.

Looking ahead, further development opportunities include introducing a broader range of weights, creating stronger end caps, and developing more intricate insert designs. These enhancements will improve the device's functionality and adaptability, allowing for more tailored and effective therapy sessions.

In conclusion, VERTIGO represents a significant advancement in tools available for vestibular rehabilitation therapy in SRAL Homewood. By addressing the limitations of current methods and providing a more engaging and customizable solution, our product has the potential to greatly enhance the therapeutic experience for patients of Dr Hardy with vestibular dysfunction.

Appendices

Appendix A: Our Project Partner and Vestibular Balance Disorder

Introduction

This report summarizes our secondary research for our project with Dr. Raelene Hardy at Shirley Ryan AbilityLab (SRAL) Homewood, outlining Dr. Hardy's clinical insight, our research into causes of vestibular disorders, and current treatment methodologies. Our mission is to develop a product designed to help our client improve therapy outcomes. Through this report, we aim to offer information about SRAL and their activities, vestibular balance disorders, and current products used in vestibular therapy.

About Our Project Partner

Our project partner is Raelene Hardy (PT, DPT) who is a doctor of physical therapy at SRALab Homewood DayRehab Center, which is a not-for-profit physical medicine and rehabilitation research hospital. It "serves adults and children with severe, complex conditions" [1]. They have five Innovation Centers focused on different conditions and areas of research: Brain Innovation Center, Spinal Cord Innovation Center, Nerve, Muscle & Bone Innovation Center, Pediatric Innovation Center, Cancer Rehabilitation Innovation Center. SRAL specializes in rehabilitation for those with conditions ranging from traumatic brain and spinal cord injury to stroke, amputation, and cancer-related impairment. Their mission statement is "providing the best patient outcomes through the highest-quality clinical care, translational research, scientific discovery and education" [2]. Shirley Ryan's aims to provide exceptional programs for its patients, give peace of mind to patients' families, and share its mission with thousands of volunteers and supporters.

Vestibular Balance Disorder

Most of our users suffer from some disruption or dysfunction in their vestibular (balance) system. Vestibular disorder is caused when a trigger is interfering with a person's body's balance system. There are many potential triggers such as medicines, infections, inner ear problems, calcium debris, and traumatic brain injury. According to [3], [4], and [5], common symptoms of vestibular disorders are dizziness, blurred vision, disorientation, and feeling as if one is floating or off-balance. This results in patients regularly falling and stumbling, resulting in other injuries or damage to the surroundings. At Shirley Ryan, a wide variety of patients can be found from ones who can walk independently to ones who cannot stand on their legs.

Vestibular balance disorder can be treated through treating underlying causes, changes in lifestyle, or surgery [3]. In this project, we are concentrating on aiding Dr Hardy in her treatment process via rehabilitation and physical therapy. Vestibular Rehabilitation Therapy (VRT) "involves exercises that help you manage dizziness and balance issues (imbalance)" according to [9]. VRT aims to increase the quality of life of the patients by reducing symptoms of dizziness, increasing body strength, and improving the ability to stabilize vision. This is achieved through intensive training in eye movement control, balance, stretching, and strengthening. Dr Hardy's therapy routine usually takes two to three months of weekly sessions, including doing exercises on their own.

Existing Solutions and Problems

Most existing solutions currently on the market utilize balance training through different surfaces. Different types of balance boards can be found such as inclined boards [6] that patients can stand on. Inflatable discs [7] are also very popular as the user can simultaneously strengthen their body and train to balance their body. Such solutions are cheap ($30 to $50) and accessible due to their simplicity. More complex products include linear balance gliders [8] that are used in therapy sessions with professionals. Gliders are more expensive reaching values of $6000, and require training and expertise to use with patients. These solutions found on the web are primarily focused on strengthening the body and balance exercises.

However, in our initial interview, Dr Hardy informed us that most of her patients suffer from eye fatigue, neck soreness, or inner ear crystals causing dizziness. Therefore, training equipment that focuses on multitasking is needed in Dr Hardy's rehabilitation activities.

In the project description, we were notified that Dr Hardy prefers using sticky notes in a variety of positions to enforce head and eye movement on the patient. This training is used to mimic walking, talking, or looking at one’s phone, which are activities we often practice in our daily lives. However, our client finds this solution inconvenient as sticky notes are not designed for therapy purposes.

Appendix B: Project Partner Interview Summary

Date: Wednesday, April 23, 2024
Attendees: Sam, Emir, Daniil, Francisco
Meeting with: Raelene Hardy, Project Partner
Objective: To gather more information before observation

Background

Dr. Raelene Hardy is a Senior Physical Therapist at Shirley Ryan Ability Lab in Homewood, Illinois. She also holds a critical dual-role of being a vestibular therapist, which involves engaging in therapeutic sessions with people who have had traumatic experiences - such as spinal-cord injuries, head trauma, or even post-covid issues - resulting in a range of persistent symptoms, including but not limited to - difficult with balance, easily provoked dizziness, difficulty with eye movements, and sensitivity to various stimuli such as loud sounds or bright lights. Often, these symptoms impede on the lives' of the patients and make daily tasks more difficult and possibly painful to complete. During these therapy sessions, Dr. Hardy works diligently with her patients and, based on their specific symptom profile, creates an activity routine in an attempt to provide relief to their vestibular deficits.

Dr. Hardy has informed us that she is in need of an innovative dual-tasking tool to address the challenges faced by patients with vestibular dysfunction in a clinical setting. She currently employs a manual technique involving drawing letters, numbers, and shapes on sticky notes, which she then places on walls or holds in her hand. This method is used to facilitate visual scanning, saccades, and dual-tasking activities while patients are sitting, standing, walking around the clinic, or using a treadmill. Dr. Hardy emphasized the potential benefits of a user-engaging, easily set-up device that patients could use in various positions to promote visual scanning and saccades. She envisions this device as a versatile tool that can be easily customized depending on the patient symptom profile. We have conducted a Zoom interview with Dr. Hardy, gaining more insight onto the issue.

Zoom Meeting (04/03/2024)

Based on our first interview with Dr. Hardy, we aim to develop a vestibular dual-tasking device that will serve the dual purpose of being engaging and effective at invoking dizziness symptoms within patients, with the ultimate goal to build resistance to vestibular symptoms occurring in the patients' daily lives. Dr. Hardy indicated that although her current methods of using sticky-notes and meter sticks are effective, she wishes that there were more innovative and engaging ways that allow for customizability and diversity during therapy sessions. She states that there is a lack of diversity regarding tools for vestibular patients. Dr. Hardy also informed of us specific therapy techniques that she uses, including: VOR cancellation (actively using both eyes and ears in an exercise), convergence (maintaining focus being brought closer to your nose), saccades (practicing rapid eye movement by queueing her patients to different objects), visual scanning, and smooth pursuit (being able to keep focus on an object as it smoothly moves in a direction). She also informed us of the importance of dual-tasking in her therapy sessions, stating that she often uses

motor-motor or motor-cognitive dual tasking in her therapy sessions. Motor-motor dual tasking is a task that engages two motor skills at the same time: such as walking in a straight line while also bouncing a ball up and down. Motor-cognitive dual-tasking is a task that engages in a motor task while also engaging cognitively. For instance, one could be walking and being asked math questions at the same time. Dual-tasking is specifically critical because it allows the patients to build a resistance to dizziness while stimulating activities they would perform in their daily tasks. Stimulating these activities and invoking dizziness within an artificial setting builds resistance to dizziness during similar daily tasks. She expressed the importance of alleviating vestibular symptoms through real-world task stimulation in her therapy, which is why a tool that is customized to any patient, is able to be used in vestibular activities, and can be used in various positions such as standing, sitting, or walking is essential for the success of her patients. Dr. Hardy additionally gave us a thorough background of her patients, explaining that the majority of them are rebuilding their skills after suffering from a stroke, concussion, or spinal cord injuries. Her patients are all on different levels of regaining their normal balance skills, highlighting the importance of an easy-to-use and customizable device. Moreover, her patients tend to be older and she told us that many of them get tired after walking 300ft while holding a popsicle stick. Getting tired easily, coupled with the lack of engagement in the tools she currently uses, highlighted the importance of an engaging and customizable device. These are tasks that the patients have to perform daily to increase their ability to effectively engage with the real world, so having the motivation (in the form of engagement) to perform these tasks is essential to the patient's success.

Appendix C: Second Meeting with Project Partner

Date: Wednesday, April 23, 2024
Attendees: Sam, Emir, Daniil, Francisco
Meeting with: Raelene Hardy, Project Partner
Objective: To gather more information before observation

Observations and Takeaways

1. **Value of Device Being Handheld:**
    - Inquiry: We inquired what value the device had if it was handheld
    - Answer: The device needs to be handheld so that it is mobile in spaces other than the treadmill
    - Takeaway: The device must be made handheld
2. **Length:**
    - Inquiry: What length should the device be?
    - Answer: The device must fit in the narrow hallway, and so should be around a meter
    - Takeaway: The device should be around a meter long
3. **Dream Scenario:**
    - Inquiry: What is your dream scenario for the device?
    - Answer: The device should really provide a lot more variety than the present, like taping notes to a meter stick
    - Takeaway: The more important purpose that the device serves is that it will expand upon the options that Dr. Hardy will have during therapy with patients..
4. **Tactile Input:**
    - Inquiry: Is tactile input necessary?
    - Answer: Tactile input is not necessary for the device
    - Takeaway: Tactile input is not a project requirement, but could be a way to engage patients
5. **Flexibility**
    - Inquiry: Should the device be flexible?
    - Answer: There’s no need
    - Takeaway: There is no value in making the device flexible, and resources should not be spent on this

Appendix D: User Observation

Date: Friday, April 26
Location: Dr. Raelene Hardy's Office, Homewood
Attendees: Sam, Daniil, Emir
Meeting with: Dr. Raelene Hardy
Objective: To observe a patient therapy session and gain firsthand insight into vestibular rehabilitation techniques.

Observations and Takeaways

Image 2: SRAL Homewood

Environment:

- **Observation:** The Homewood office of the Shirley Ryan Abilitylab is a brightly-lit, bustling space with multiple communal spaces as well as private therapy rooms. The clinic provides numerous types of therapy. Dr. Hardy highlighted that the clinic's bright, warm colors can be overwhelming for vestibular patients.
- **Takeaway:** Our product must be able to be used either in a large open space or in the smaller rooms.

Patient Interaction:

- **Observation:** We met Dan, a patient dealing with long-term effects of COVID-19, including extreme light sensitivity. Dr. Hardy highlighted that the clinic's bright, warm colors can be overwhelming for vestibular patients.
- **Takeaway:** Our product design should avoid bright lights and mirrors to accommodate patients with light sensitivity and to create a more soothing environment.

Patient Exercises:

- **Observation:** Dan performed self-guided exercises, facing challenges such as prolonged standing, rapid eye movements, and neck muscle exercises. We noticed (and Dr Hardy privately corroborated) that stress tended to exacerbate his symptoms.
- **Takeaway:** Our product should help reduce the difficulty of standing, improve rapid eye movement exercises, and support neck muscle exercises. It should also avoid competitive elements to minimize stress.

Dual-Tasking Exercises:

- **Observation**: Dan's dual-tasking exercises involved walking a line while tossing and tracking a miniature basketball.
- **Takeaway:** Our product needs to complement the existing dual-tasking exercises, either by providing new exercises or optimizing the existing ones.

Additional Therapy Methods:

- **Observation:** Other methods in the clinic included eye-tracking goggles and a large digital touchscreen for peripheral vision and hand-eye coordination tests. Dr Hardy indicated that she is content with her current use of these devices.

- **Takeaway:** Our product should need not replace those additional devices, and should instead be solely a handheld dual-tasking device.

Conclusion

The visit to Dr. Hardy's office provided insights into vestibular therapy, helping us understand the specific needs and challenges of her patients. Our observations led to the following takeaways:

1. **Design Considerations:** Avoid bright lights and mirrors; handheld cylindrical design around 30 inches long; adjustable weight up to 3 lbs.
2. **Functional Requirements:** Incorporate a range of cognitive tasks with varied difficulty and multiple language options to cater to patients with different literacy and numeracy levels.
3. **Stress Management:** Eliminate competitive elements to avoid adding mental pressure on patients.

By integrating these insights, we aim to develop a product that enhances Dr. Hardy’s ability to conduct effective and comprehensive vestibular rehabilitation.

Appendix E: Design Review Summary

Date: Wednesday, May 9
Presentors: Daniil, Sam, Francisco, Emir
Consulting: Professor Bishop, Professor Andrew, and Class
Objective: Present our design concept and receive feedback

During Design Review, we created a presentation of our design concept and presented it to our class and professors to get feedback. The feedback that we received is detailed below, along with how we intend to alter our design due to the feedback.

Cylinder Protection:

- Feedback: The outside of the cylinder should have some kind of protection to prevent breakage if it falls.
- Suggestion: Consider adding material around the caps on each end of the cylinder for protection.

Interactive Elements:

- Feedback: Other interactive elements are beneficial to consider.
- Suggestion: Incorporate additional interactive features to enhance user engagement.

Cylinder Diameter:

- Feedback: The cylinder should be roughly 2 inches in diameter, based on feedback and observations of another team's mockups.
- Suggestion: Adopt the 2-inch diameter size as it has been found to be very effective.

Marble Maze Game:

- Feedback: More input on the idea of a marble navigating through a maze; the marble could move upward through the cylinder if there are no weights.
- Suggestion: Explore ways to allow the marble game to be used by multiple people, passing it on after reaching a checkpoint.

Maze Variations:

- Feedback: Consider different maze types such as a flat maze for a disk (not a marble), adding a textured middle section to produce sound or provide tactile feedback when a marble passes through, and the middle section could make noise.
- Suggestion: Develop various maze configurations to provide different sensory inputs and challenges.

Cylinder Caps:

- Feedback: PVC caps should be threaded and hold very tightly.
- Suggestion: Ensure that the caps are securely threaded to maintain the integrity and functionality of the device.

Cap Protection:

- Feedback: Foam bumpers should be added to the caps for extra protection.Suggestion: Implement foam bumpers to safeguard the ends of the cylinder, enhancing durability.

Appendix F: Third Meeting with Project Partner

Date: Wednesday, May 1, 2024
Attendees: Daniil
Meeting with: Raelene Hardy, Project Partner
Objective: Present design and gather feedback about specifications before finalizing design.

Observations and Takeaways

- **Weight of Tool**
    - Baseline max weight of 3lb
        1. Patients' arms fatigue quickly
    - Prefers three weight options: 2.5lb, 5lb, and 10lb
        1. Patients often shake and require the input of the weight in order to stop shaking

- **Designs**
    - 10 Baseline Designs
        1. Alphabet
        2. Counting numbers
        3. Color words
        4. Months
        5. States
        6. Simple Shapes
        7. Animal outlines
        8. Alternating shapes with different colors
        9. Marble maze
        10. Plain background for smooth pursuit
    - Insert for her own designs
        1. Has patients with very unique needs and would like to customize visuals for them.
    - Similar designs should be front & back
    - Black designs, light background

- **Overall Design:**
    - Likes the structure and easiness of the tool
    - Enjoys that inserts and weights can be easily taken out or put in

Conclusion:

- Provide her with 10 baseline designs and an insert so she can create her own designs.
    - Similar designs should be front and back
    - Black letters, light background

- Maintain our current overall design
- Provide three weights for maximum weight customizability

Appendix G: Shop Consultation

Date: Wednesday, May 15
Attendees: Sam, Emir
Meeting with: Joe Keuchel, Shop Expert
Objective: To discuss specific aspects of the product design related to securement and stability.

Observations and Takeaways

1. **Securing End Caps:**
    - Inquiry: We inquired about the best method to secure the end caps for our device.
    - Answer: Joe recommended against using threaded PVC end caps and suggested 3D printing the end caps instead.
    - Takeaway: We will 3D print the threaded end caps to ensure a precise fit and better integration with the overall design.
2. **Stabilizing Weighted Rods:**
    - Inquiry: We needed a solution to keep the weighted rods stable within their casings to prevent rattling or shaking.
    - Answer: Joe advised using low-expanding spray foam inside the plastic casing to secure the rods.
    - Takeaway: Incorporating low-expanding spray foam will provide stability to the weighted rods, preventing movement and noise.
3. **Securing Weight Casings Within the Tube:**
    - Inquiry: We sought advice on how to keep the weight casings securely in place within the tube.
    - Answer: Joe recommended using brackets at the beginning and end of the tube to hold the weight casings firmly.
    - Takeaway: Implementing brackets at both ends of the tube will ensure the weight casings remain securely positioned during use.
4. **Ease of Inserting Weights and Visual Section:**
    - Inquiry: We wanted to make it easy to insert the weights and the visual section into the device so they align correctly with the brackets.
    - Answer: Joe suggested beveling the end bracket to allow the pieces to slot smoothly into place.
    - Takeaway: Beveling the end bracket will facilitate the easy and accurate insertion of the weights and visual section, ensuring proper alignment and secure placement.

Conclusion

Our consultation with Joe Keuchel provided valuable solutions for securing and stabilizing the components of our device. The key takeaways from this discussion are:

1. End Caps: Opt for 3D printing for precise and secure end caps.
2. Weighted Rods: Use low-expanding spray foam to stabilize the rods within their casings.
3. Weight Casings: Implement brackets at both ends of the tube to secure the weight casings.
4. Insertion Ease: Bevel the end bracket to ensure smooth and accurate insertion of components.

These insights will enhance the overall stability and usability of our product, contributing to a more reliable and user-friendly design.

Appendix H: Bill of Materials

Table 1: Bill of Materials

Material	Specifications	Quantity	Vendor	Unit Price ($)	Price ($)
Clear-view PVC pipe	Size: 2 Length: 4’	1	McMaster Carr	71.18	71.18
Neodymium cylindrical magnet	Diameter: ¼” Height: ¼”	6	McMaster Carr	1.20	7.20
Assorted Acrylic Paints	Colors: black, purple, blue, red, gray, yellow Size: 16 oz	6	Amazon	4.93	29.58
1144 Steel	Diameter: ½” Length: 3’	1	Workshop	11.23	11.23
Glass Marble	Diameter: ½”	1	Francisco	0.50	0.50
Very High Peel Strength Epoxy	3.5 grams	3 packets	Ellsworth Adhesives	1.61	4.83
PLA Filament	3 grams	4	Mudd Library	~1	~4

Total Materials Cost: $128.52

Appendix I: Methods of Construction

VERTIGO is highly adaptable, but any way it is built consists of three main components: The inserts, the brackets and end caps, and the weight.

Image 3:

Creating the Inserts

1. Cover a 24”x36” (6mm thickness) piece of birch plywood with strips of blue tape on both sides (see image at right)
2. Use a vector image software (such as Adobe Illustrator or CorelDraw) to generate rectangles of dimensions 900 mm x 40mm with the desired designs inside. Use red lines to indicate the boundaries (what part of the wood should be cut through) and black fill to indicate the designs.
3. With the sheet of taped plywood in the laser cutter, set the strength of the laser to 1% speed, 100% power for the red lines and 70% speed, 80% power for the black graphics.
4. After the designs are etched, flip over the board, taking care to orient the newly-cut inserts as desired, and repeat steps 2 and 3 to engrave designs on the reverse-side

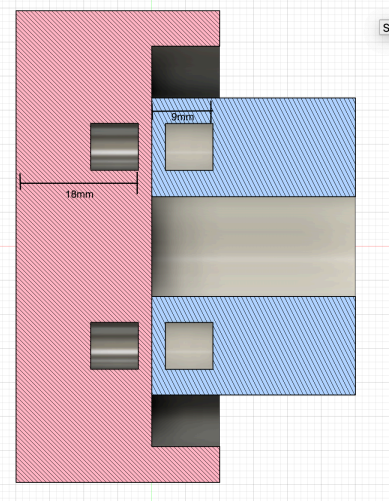
Image 4:

5. After the laser is finished cutting and engraving, delicately paint the inserts with the desired acrylic paint color (see image at right)
6. When the paint is finished drying, carefully remove the tape. Use various abrasive materials such as files, sandpaper, and Dremel attachments to remove unwanted paint, and to smooth out all edges and corners. Use a vacuum and a cloth to remove splinters and sawdust.
7. Once all of the tape is removed, pour teak oil onto the inserts. Use a cloth to spread it around. Two coats are recommended.
8. It is ideal to wait 72 hours after applying the teak oil to apply a topcoat, but 24 hours should be alright. Use a large synthetic paintbrush to cover all surfaces evenly in a thick polyurethane topcoat.
9. After 24 hours, use high-grit sandpaper to polish and remove streaks. Repeat steps 8 and 9 if desired for smoother finish.

Image 5: CAD Design of End Caps

Creating the Brackets and End Caps

The brackets fit within the tube, and the end caps fit around the tube.



1. Use CAD software (such as Fusion360) to create 3D models of the brackets and end caps. The front set should have spaces for embedded magnets about 2mm deep (see image at right), and the rear set can be solid. STL files are available upon request
2. 3D print each bracket and end cap one at a time. For the set that contains magnets it is easiest to have the g-code pause the 3D printer at the correct height to insert the magnets. Ensure the poles of the magnets are facing the correct directions

Creating the Weight

1. Cut a ½” diameter steel rod to length and use various abrasive devices to round the edges
2. Paint the rod
3. Use multiple turns of blue tape at each end to ensure a flush fit when inserted into the bracket

Image 6: End Design

Putting it all together

1. Mix together the components of the two-part epoxy with a popsicle stick on a piece of cardboard. Apply it to the first ¼” of each end of the tube, and the first ¼” of each bracket. Ensuring the slots and holes on the brackets are aligned, slide each bracket into an end of the tube, stopping when the ends are flush
2. After the epoxy cures (allow 24 hours) take the rear bracket (the one with no magnets) and epoxy it to the rear end cap (the one that does not have holes that pass all the way through).

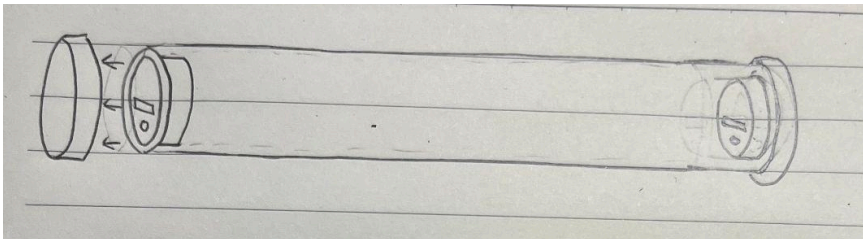
Appendix J: Instructions for Use

Starting with an empty device (if non-empty start with the **Unloading** section to remove any inserts):

Loading

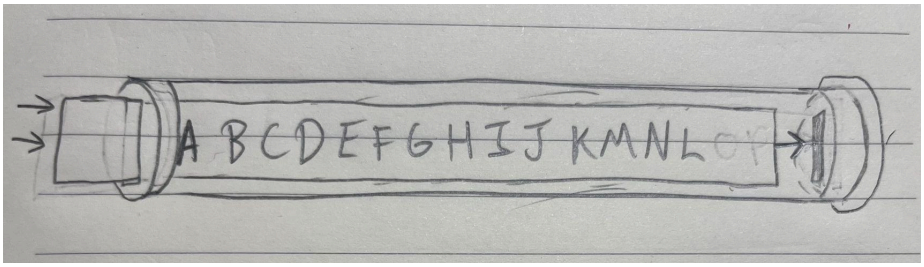
1. Begin by removing the magnetically attached cap of the device as seen in Image 7

Image 7: Uncapping the device



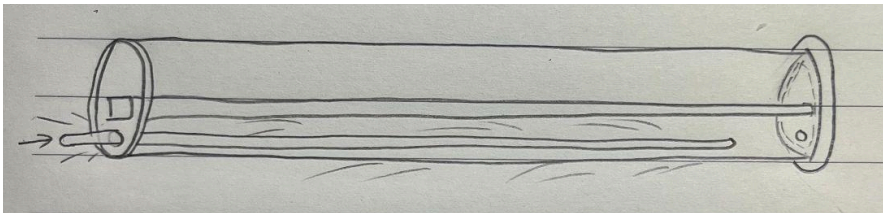
2. Then load the tube with any insert desired, by rotating the device so that the circular hole will be invisible from the front. See Image 8. If using a marble, then load the marble through the circular hole located below the slit for the inserts, and use the respective insert.

Image 8: Loading the tube with an insert, in this case the alphabet (see Step 4)



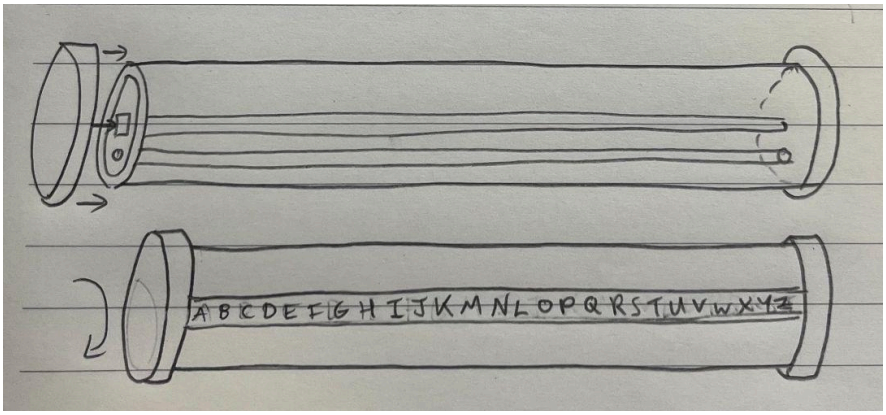
3. Optional: Load the tube with the weight, with the device rotated so that the circular hole is below the insert's hole, as seen in Image 9.

Image 9: Inserting weight



4. Place the cap on, and it will attach magnetically. Then rotate to the side that will cover the weight.

Image 10: Placing the cap, and then rotating so that the inserts' engravings are visible



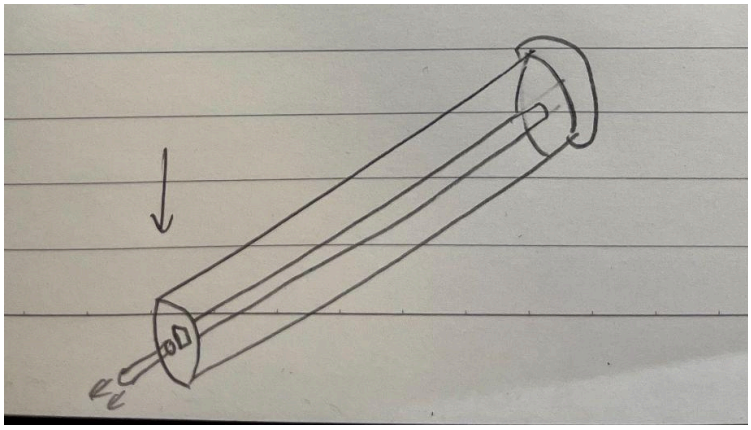
Use In Vestibular Therapy

Begin exercises (determined by vestibular therapist - can include scanning from side to side or manipulation of marble)

Unloading

1. Remove the end cap as shown in Image 7, and then rotate to one side, to let gravity remove the weight and then insert, as seen in Image 11. If the marble was loaded, then let the marble fall to one side and aim for it to exit through the weight's hole.

Image 11: Removing the weight & inserts.



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