Preliminary Report: Dynamic Balance Device

Biomedical Engineering 301

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Abstract

Approximately 30% of post-stroke patients experience Spatial Neglect Syndrome, which impairs balance and increases their fall risk, slowing their recovery [1]. Current rehabilitation methods are either rudimentary, such as a yardstick, or expensive, such as a large stationary display. Previous design iterations were too heavy for the client to use repeatedly, or they weren't durable enough, and insecure in their attachments. This project aims to develop a lightweight and durable Dynamic Balance Device to improve visuomotor training and balance rehabilitation for post-stroke patients. The final design includes a fixed length carbon shaft with an integrated measurement along the length. There will be a 56.25 cm^2 display at the end and a sensor-activated speaker. Carbon fiber was selected as the material choice due to its lightweight characteristics and unmatched strength-to-weight ratio. Testing plans include MTS analysis to measure elastic modulus and toughness, while qualitative surveys will be completed with the client to assess comfort and perceived weight. The battery for the electronics portion will also be tested to ensure it can be used for long periods of treatment. This device will be under the budget of $500, and will serve as an alternative to the yardstick with a sticky-note, and will reduce provider strain in the clinic.

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Introduction

A. Motivation

Falls are the leading cause of injury-related death in adults aged 65+, attributed to decreases in balance and mobility that come with old age [2]. Stroke is a common disease that about 25% of adults over the age of 25 will experience during their life [3]. Among stroke survivors, about 30% of patients experience Spatial Neglect Syndrome or lose vestibular sense, leading to falls that set back their recoveries [1]. Spatial Neglect Syndrome is most commonly caused from hemispheric stroke and is more severe and persistent in acute cases caused by damage to the right hemisphere of the brain [4]. In these acute cases, about 50% of patients suffer from Spatial Neglect Syndrome. Spatial Neglect Syndrome severely impairs the patient's ability to understand spatial relationships such as depth perception and representation of space. Physical therapists have found successful therapies to retrain the brain to better understand these spatial relationships following stroke, however, existing devices are either too expensive or too heavy for practical use. The client for this project, Mr. Daniel Kutschera, saw a need to improve the complexity and ergonomics of devices used for Spatial Neglect Syndrome rehabilitation. The goal of this project is to create a device that implements both auditory feedback and color-coded visual feedback to these devices to aid in the rehabilitation of stroke patients suffering from Spatial Neglect Syndrome.

B. Existing Devices

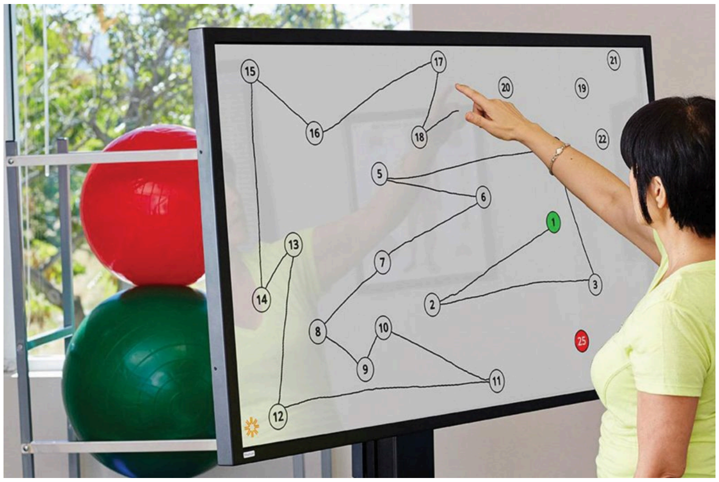


Figure 1: Bioness Integrated Therapy System [5]

The Bioness Integrated Therapy System (Figure 1) is an existing device used to improve cognitive training, hand-eye coordination, peripheral awareness, reaction time, and standing tolerance [5]. This device is a touch screen that has a variety of programs that are used to personalize the therapy to match where the patient is at in their recovery. It also allows for the physical therapist to use both of their hands to help support the patient. This device typically ranges from $12,000 to $22,000 depending on whether the therapist would like additional accessories or needs additional permits [6].

Previous BME design teams have developed devices to improve upon the client's current device, a yardstick with a sticky note at the end. These devices have implemented electronic components with changing colors and buttons to control the colors shown on the display screen. However, these devices have been too heavy for practical use and have not been durable enough to withstand the therapy that the client does.

C. Problem Statement

Patients that have suffered strokes have a 30% rate of developing Spatial Neglect Syndrome [1]. Symptoms of Spatial Neglect Syndrome include loss of awareness of the body in space and impaired spatial relationships. Our client, Mr. Daniel Kutschera, a physical therapist, helps patients to regain strength and balance following a stroke. The client is currently using a yardstick with a sticky note at the end and asks patients to reach towards the sticky note to help rebuild spatial relationships in their brain. The client seeks to develop a device that can be used to improve visual scanning and balance training that is lightweight and more complex than his previous design. The device should be multi-functional so as to help patients with varying degrees of need and be effective in the rehabilitation treatment.

Background

A. Background Research

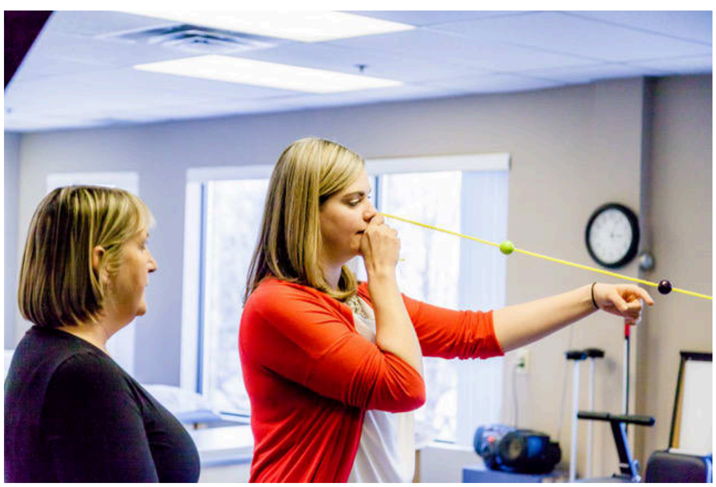


Figure 2: Visuomotor Training [8]

Stroke patients are at an increased risk for developing Spatial Neglect Syndrome, resulting in a lack of understanding the representation of space and impaired spatial attention [4].

Specifically, about 30% of patients that have suffered from stroke experience Spatial Neglect Syndrome and patients that have had damage to the right hemisphere of the brain are at an even greater risk [1]. Spatial Neglect Syndrome often results in an increased risk for falling due to difficulty balancing that can significantly slow down the recovery process.

Physical therapists use targeted therapies with patients suffering from Spatial Neglect Syndrome to improve spatial relationships. One of these therapies is called visuomotor training which involves the physical therapist asking the patient to reach towards an object to help the patient's brain relearn depth perception and spatial relationships [8]. This therapy typically lasts about 15 minutes per patient and is performed by the physical therapist 5-6 hours a day, 5 days a week. Due to the fact that the device needs to be held in an extended outward position by the physical therapist, strain is common due to the prolonged and repetitive use of these devices.

B. Design Research

In order to create a device that can be comfortably held for prolonged periods of time, it is necessary that the bulk of the electronics are distributed in a way that makes the perceived weight of the device less than or equal to the actual weight [9]. Therefore, the electronic components must be at the end of the device with the handle in order to reduce the effects of torque. To help stabilize the device, a counterweight will be added, likely the electronic components, to help stabilize the mechanism for the physical therapist. A counterweight works by providing an equal and opposite torque on one side of the device to balance the torque generated from the opposite side [10]. For the auditory component of the device, capacitive sensors are a helpful electronic device that can be implemented to provide ease for both the client and patient. These sensors are activated by introducing stimuli close to them. The capacitive sensors vary in sensitivity which will make it so that the patient does not need to perfectly reach the desired length for the sensors to accurately activate.

C. Client Information

Mr. Daniel Kutschera is a physical therapist for ThedaCare, an acute stroke clinic in Fitchburg, WI. His therapy specializes in stroke rehabilitation, specifically for patients suffering from Spatial Neglect Syndrome.

D. Design Specifications

The device must meet specific requirements outlined by the client and follow the Product Design Specification outlines (see Appendix A). The device must be 10% lighter than the previous design which weighed 0.36 kg and the electronic display at the end must be 7.5 cm across or 56.25 cm^2. The electronic display must have the ability to display various colors. The shaft of the device must be at least 61 cm long and include a measurement system that allows the client to perform a functional reach test with his patients to track their progress. The device must also be made using a material that can be frequently sanitized and durable. The total cost of the project must not exceed $500.

Preliminary Designs

A. Auditory Feedback Designs

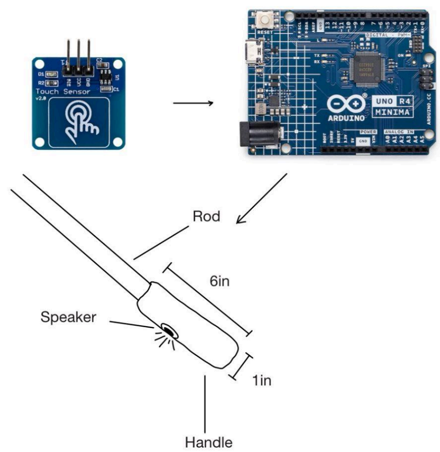


Figure 3: Sensor-Activated Speaker Design

The first design considered for the auditory feedback matrix is the Sensor-Activated Speaker. This design incorporates a capacitive touch sensor to allow a hands free activation of the speaker. When the user touches the sensor, the Arduino, along with the microcontroller code in Arduino IDE, activates a small speaker embedded in the handle. This design emphasizes simplicity and low effort for the user, so the client can focus on supporting the patient. This design also allows for a variety of different sounds to be programmed into the device, allowing for different feedback.

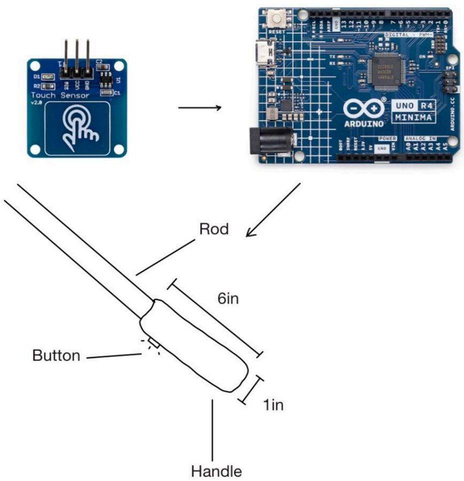


Figure 4: Sensor-Activated Noisemaker Design

The second design replaces the capacitive touch sensor with a physical push button. The button is wired to the circuitry containing the Arduino. When the sensor is activated, the coding in Arduino IDE will be such that the auditory feedback noisemaker is triggered. An advantage of this design is that it is more lightweight than the speaker, but this requires more precise 3D modeling and fabrication.

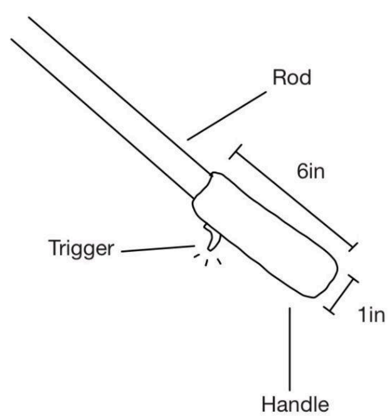


Figure 5: Manual Trigger Design

This design uses the trigger as the input for the auditory feedback. As opposed to the capacitive sensor or button, the pulling of the trigger activates the mechanism. This design of the handle could be more ergonomic for the user. However, this design requires the most effort for the user and is the least effective at achieving the ease of use and effectiveness the client requires.

B. Material Designs

Figure 6: Carbon Fiber Design [11]

Carbon Fiber is an extremely lightweight material with high strength to weight ratio, making it well suited for a project that is prioritizing comfort for the client when supporting the device. It has high tensile strength, ranging from from 3,500 MPa to over 7,000 MPa allowing it to withstand repeated use without deformation [12]. Carbon fiber is also sterilizable and will not be affected by disinfectant wipes. Carbon fiber cannot be 3D printed, so this will have to be carefully machined in the TEAM lab, especially since it is an expensive material.

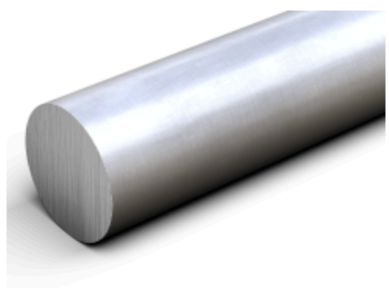


Figure 7: Aluminum Alloy Design [13]

Aluminum alloy is a strong but lightweight material commonly used for medical application. It offers mechanical strength while being easy to fabricate. Aluminum naturally forms a passive oxide layer which results in improved corrosion resistance. The tensile strength of a common aluminum alloy ranges from 228-572 MPa [14]. This material requires machining in the form of the mill and lathe.

Figure 8: PVC Tubing Design [15]

PVC tubing is a lightweight thermoplastic material, which will be easier to source and fabricate with. It is resistant to moisture so it will withstand sterilization and daily use. PVC will be easy to machine with a mill or lathe. PVC has lower tensile strength, about 31-60 MPa, so it will be easier to work with, but may not be as durable as needed [16].

C. *Overall Designs*

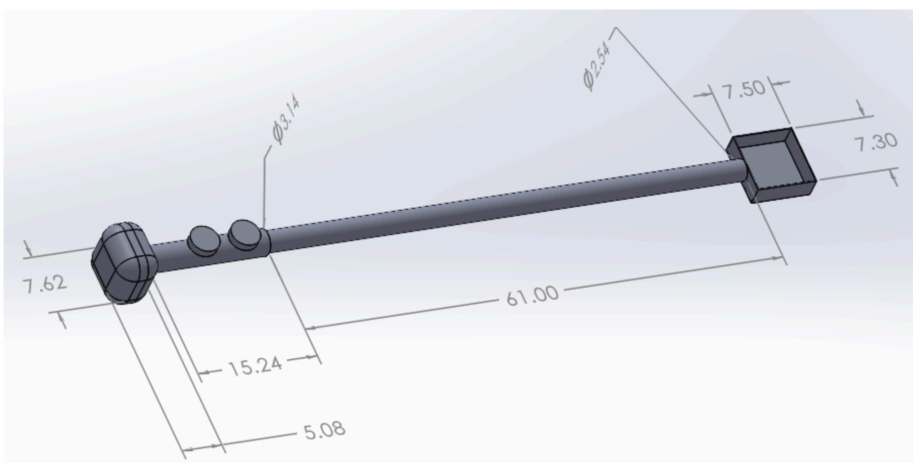


Figure 9: Fixed Length Shaft Design

This design features a rod connected to a display at the end. The handle includes a button to change the color of what is being displayed, and a switch to turn the display on and off. The control buttons are placed at the end of the handle so they are easily accessible, while the power button is placed lower so it is not accidentally activated in use. The display is the visual output component, using a screen to display different colors and shapes. This design is customizable to what the client would like to show based on the options that are coded by the group.

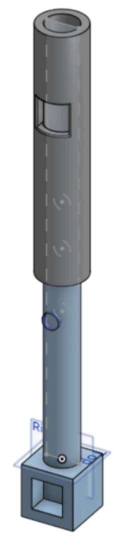


Figure 10: Push Button-Pin Shaft Design

This design includes a cylindrical upper casing display mounted vertically onto the rod. The casing includes the electronic components. This design extends from the base fixed-length shaft by adding new sections to extend and maintain the length of the device. This aspect of the design can make it more accessible for some users. The visual display fits into the box on the lower end, similarly to the fixed-length shaft. The control buttons are also placed similarly to the fixed-length design.

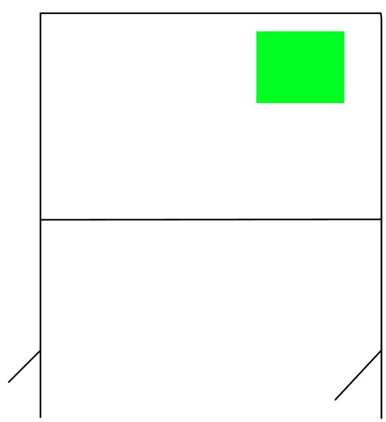


Figure 11: Hands-Free Board Design

This design is a shift from the handheld design to a larger stationary panel display. There is a board mounted on supports, with a large screen that could display anything the client wanted to use. The design shown here is a shape, which would allow the patient to practice pressing buttons or tracking shapes. This design shows a high visibility, complex output making it suitable for patient use. This will be a hands free design that lowers the burden on the provider, but the display is a much more expensive option and could be beyond the scope of this project.

Preliminary Design Evaluation

A. Auditory Feedback Design Matrix

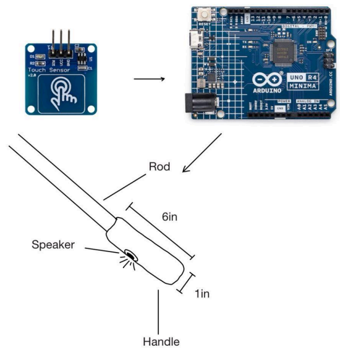
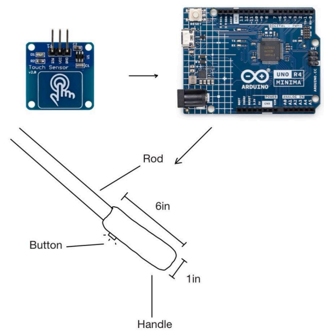
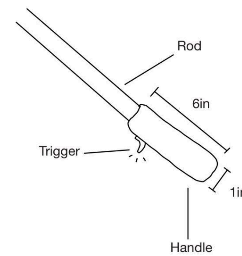
<table>
<tr><td colspan="2">Designs</td><td colspan="2">Design 1:
Sensor-activated Speaker
</td><td colspan="2">Design 2:
Sensor-Activated Button
</td><td colspan="2">Design 3: Manual Trigger
</td></tr>
<tr><td>Rank</td><td>Criteria</td><td>Score</td><td>Weighted Score</td><td>Score</td><td>Weighted Score</td><td>Score</td><td>Weighted Score</td></tr>
<tr><td>1</td><td>Weight (35)</td><td>3/5</td><td>21</td><td>4/5</td><td>28</td><td>4/5</td><td>28</td></tr>
<tr><td>2</td><td>Ease of Use (30)</td><td>5/5</td><td>30</td><td>5/5</td><td>30</td><td>3/5</td><td>18</td></tr>
<tr><td>3</td><td>Ease of Fabrication (20)</td><td>4/5</td><td>16</td><td>2/5</td><td>8</td><td>4/5</td><td>16</td></tr>
<tr><td>4</td><td>Sound Variability (10)</td><td>5/5</td><td>10</td><td>3/5</td><td>6</td><td>3/5</td><td>6</td></tr>
<tr><td>5</td><td>Cost (5)</td><td>3/5</td><td>3</td><td>3/5</td><td>3</td><td>5/5</td><td>5</td></tr>
<tr><td>Total:</td><td></td><td></td><td>80</td><td></td><td>75</td><td></td><td>74</td></tr>
</table>

Table 1: Auditory Feedback Design Matrix

Criteria:

Weight (35):

Weight is ranked as the most important criterion because excessive weight was a significant issue identified by the client in previous iterations of the device. Since the auditory feedback system is an additional feature being integrated into the existing design, it is essential that it does not increase the overall weight of the device by a large amount. The selected components must be lightweight and compact to ensure that the final prototype is lighter than previous versions.

Ease of Use (30):

Ease of use refers to the level of additional input required from the physician in order to activate or receive auditory feedback. The device should operate intuitively and integrate seamlessly into therapy sessions without requiring extra switches, buttons, or manual inputs. This ensures that the clinician can focus entirely on supporting and monitoring the patient rather than managing device controls. This criteria is weighted highly in order to prioritize patient safety and so as to not give extra work to the client.

Ease of Fabrication (20):

Ease of fabrication evaluates how complex it would be to integrate the auditory feedback system into the existing device architecture. This includes considerations such as modifying current circuitry, writing and debugging additional code, integrating new sensors or output components, such as a speaker, and producing any required 3D-printed housings or mounts.

Sound Variability (10):

Sound variability refers to the system's ability to adjust volume or tone to accommodate different patient needs. For example, patients with hearing impairments may require higher volume levels or specific frequency ranges to perceive feedback effectively, that may be too loud for other patients. Additionally, varied sounds for positive or negative feedback can potentially improve patient outcomes. Although customizable auditory feedback would enhance usability and inclusivity, it is not essential for basic device functionality. Therefore, this criteria is weighted lower than core functional considerations such as weight and ease of use.

Cost (5):

Cost is assigned the lowest weight because the project does not have strict financial constraints. The client has provided a flexible budget, allowing design decisions to prioritize performance, reliability, and usability over price. Furthermore, the potential design options are expected to fall within a similar cost range, reducing the impact of cost differences on decision-making. Therefore, cost will likely not be a determining factor.

Score Explanation

The design matrix uses the criteria above to determine the best design. For weight, both the sensor-activated button and manual trigger scored the highest due to the lower amount of components. For ease of use, both the sensor-activated speaker and the sensor-activated button scored the highest due to the sensor-based, automatic activation. For ease of fabrication, the sensor-activated speaker and manual trigger scored the highest due to the addition of new parts into the device. For sound variability, the sensor-activated speaker scored the highest due to its availability with other sound modules. For cost, the manual trigger scored the highest, due to the lack of as many electronic components as the other designs. Overall, the sensor-activated speaker scored the highest.

A. *Material Design Matrix*

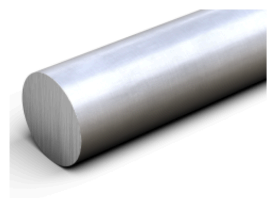
Designs		Design 1: Carbon Fiber 		Design 2: Aluminum Alloy 		Design 3: PVC Tubing 	
Rank	Criteria	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
1	Weight (40)	5/5	40	2/5	16	3/5	24
2	Durability (30)	5/5	30	5/5	30	4/5	24
3	Ease of Fabrication (15)	1/5	3	3/5	9	5/5	15
4	Ease of Engraving (10)	2/5	4	4/5	8	4/5	8
5	Cost (5)	3/5	3	4/5	4	5/5	5
Total:			80		67		76

Table 2: Materials Design Matrix

Criteria

Weight (40):

Weight is ranked as the most important criteria because excessive weight was the primary concern raised by the client regarding the previous prototype. A reduction in weight is therefore critical to improving overall usability. The selected material must be as lightweight as possible while still meeting strength requirements. This will improve user comfort and reduce physical strain, particularly in a clinical setting where the device will be used repeatedly throughout the day. Additionally, lowering the weight contributes to patient safety by minimizing the risk of injury if the device is dropped or mishandled.

Durability (30):

Durability is ranked as the second most important criteria due to issues with structural failure in previous prototypes. The final design is expected to have a minimum life in service of one year with minimal maintenance. Therefore, the selected material must possess sufficient strength in order to not bend or break due to bending stresses from normal use. It should also demonstrate resistance to wear and impact from patients that can be encountered in a clinical environment. Ensuring durability will increase longevity and overall performance of the device.

Ease of fabrication (15):

Ease of fabrication is given a slightly lower weighting because the design requirements involve minimal complex manufacturing processes. The material will be purchased in tubular form, reducing the need for most fabricating techniques. Any additional fabrication such as cutting, drilling, or finishing will be carried out using tools available in the TEAMLab on campus. Although the fabrication process will be straightforward, the material should still be compatible with available tools and processes to ensure safe and accurate construction of the prototype.

Ease of Engraving (10):

Ease of engraving evaluates how effectively measurement markings can be permanently applied to the material. The final prototype must incorporate a clear and accurate measurement system so that the client can collect reliable data during functional reach tests. The material should allow for precise engraving, etching, or marking without compromising structural integrity. While this is an important feature for usability and data accuracy, it is not weighted as highly because alternative marking methods such as vinyl decals, adhesive scales, or stenciling can be used if direct engraving is outside of the scope of this project.

Cost (5):

Cost is assigned a lower weighting because performance characteristics such as weight and durability are of greater importance for this project. As only a single prototype will be manufactured, material cost does not significantly impact the overall design. Furthermore, the client has provided a flexible budget, allowing material selection to be guided primarily by functionality rather than price constraints. However, cost is still considered to ensure responsible purchasing choices and to maintain the potential for future scalability if additional units are to be made.

Score Explanation

This design matrix also uses the criteria above to determine the best design. For weight, carbon fiber scored the highest, due to its low relative density. For durability, carbon fiber and aluminum alloy scored the highest due to their high tensile strength. For ease of fabrication, the PVC tubing scored the highest, due to how it can be worked on with multiple CNC machines. For ease of engraving, aluminum alloy and PVC tubing scored the highest due to the compatibility they have with mills. For cost, the PVC tubing scored the highest, due to its availability and price per gram.

B. Overall Design Matrix

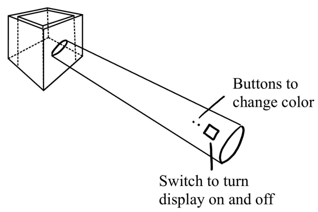
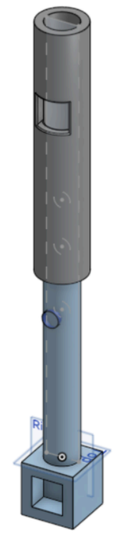
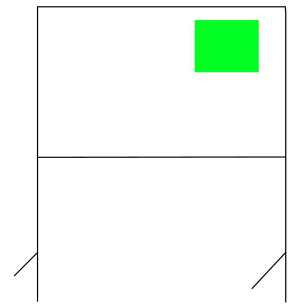
Designs		Design 1: Fixed Length Shaft 		Design 2: Push Button Pin Shaft 		Design 3: Hands Free Board 	
Rank	Criteria	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
1	Weight (25)	4/5	20	4/5	20	5/5	20
2	Durability (25)	5/5	25	4/5	20	4/5	20
3	User Comfort (20)	4/5	16	4/5	16	3/5	12
4	Ease of Fabrication (15)	5/5	15	3/5	9	2/5	6
5	Safety (10)	5/5	10	4/5	8	4/5	8
6	Cost (5)	5/5	5	4/5	4	1/5	1
Total:			81		77		67

Table 3: Overall Design Matrix

Criteria:

Weight (25):

Weight evaluates numerically and experimentally how heavy the final design will be perceived by the user. The product is intended to be in use while the client is physically supporting patients, so a manageable weight is a key factor in how easily this can be done. In addition, if the device is too heavy it might degrade faster or fail at attachments. Weight will be evaluated as better or worse than the previous design, which was deemed too heavy. If the device is too heavy and it hinders the client's ability to support the patient, the patient could face a safety risk. Since weight impacts comfort, durability, and safety, it is given the highest weighting of the criteria.

Durability (25):

Durability refers to the device's ability to withstand use for 8 hours a day 5 days a week. The device will be durable if it does not require frequent servicing. Durability also specifies that the attachments should be especially secure, since the previous designs have failed at the attachments. Durability can include the material strength and also the integrity of the design. If the device is not durable enough the device will be unsafe for the patient, so durability is very important for the chosen design.

User Comfort (20):

User comfort evaluates how easy it will be for the user to effectively use the final product. This includes how much the user's hand needs to extend to change the color of the light displayed at the end of the device, the grip used to hold the device for extended periods of time, and the user's confidence with using the final product for therapy. This criteria is important because this design has previously lacked comfortability for the user.

Ease of Fabrication (15):

Ease of fabrication describes the complexity of the design and evaluates how complicated the design would be to fabricate. This includes any 3D printing, machining, and circuitry. This criteria is important in order to determine if the proposed design would be able to be fabricated during the timeframe for this project and with the given resource constraints. However, this criteria is not the most important as there is only one prototype being fabricated opposed to multiple that need to be easily replicated.

Safety (10):

Safety describes the potential risk of injury due to sharp edges, exposed circuitry, etc. in order to choose a design that reduces the risk of injury for the user. This criteria is weighted low as all of the design ideas will have the circuitry safely enclosed and include rounded edges in order to avoid harming the user.

Cost (5):

Cost evaluates the expense for fabricating each design. This criteria is weighted the lowest because all of the designs have a similar complexity and will easily remain in the budget provided. The overall cost will ultimately be determined by the material chosen which will be evaluated in the material matrix.

Score Explanation

Regarding weight, the hands-free board scored the highest, due to the physician not needing to hold the board up during its usage. For durability, the fixed length shaft scored the highest due to a lower amount of openings compared to the push button pin shaft. For user comfort, the fixed length shaft and push button pin shaft scored the highest due to their maneuverability and weight dispersion. For ease of fabrication, the fixed length shaft scored the highest, due to the singular main piece that holds up the bulk of the material. It removes steps that would be necessary with either other design. For safety, the fixed length shaft scored the highest due to how the physician can use and hold it, along with how it doesn't need to have a button where things could possibly get stuck. For cost, the fixed length shaft scored the highest due to needing fewer mechanical components.

Proposed Final Design

The proposed final design combines aspects from each of the listed matrices. The fixed-length shaft is implemented as the bulk of the design, constructed with carbon fiber. The handle will contain an internal compartment for storage of the power source, as well as buttons to turn the display on and off and change the colors of the display. The sensor activated speaker will be implemented in the box at the end of the carbon fiber tubing. This device will use a sensor activated speaker to perform a tactile, immediate response when a reach test is performed by the client in the physical therapy setting. The LED component will also be kept in this end portion, allowing for different colors to be displayed. The LED will be compatible with an Arduino microcontroller that will allow for simple commands to be transmitted [17]. Overall, the device will prioritize maintaining a light weight, being ergonomic, stable, affordable, and easy to use, being ideal for clinical and therapeutic settings that perform visual and balance training with patients.

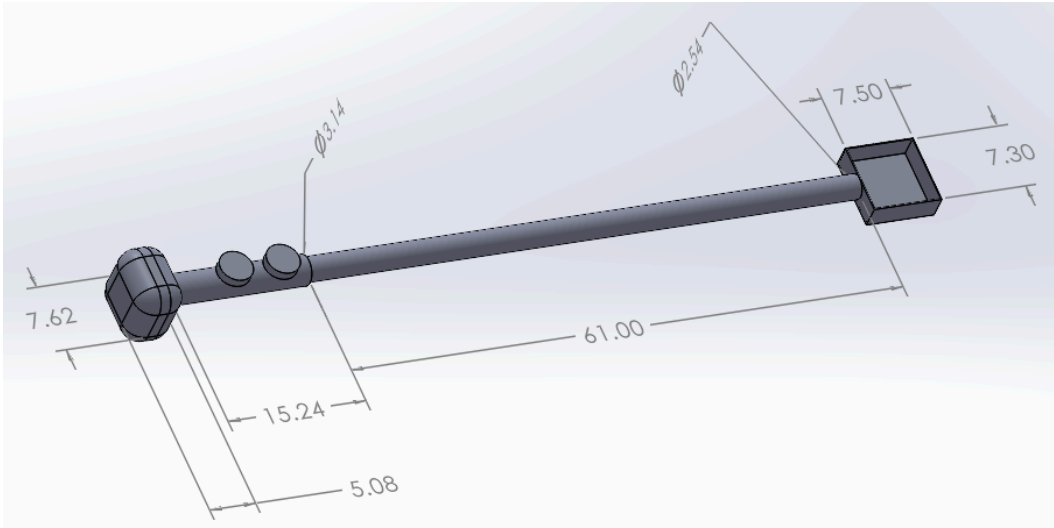


Figure 12: Proposed Final Design.

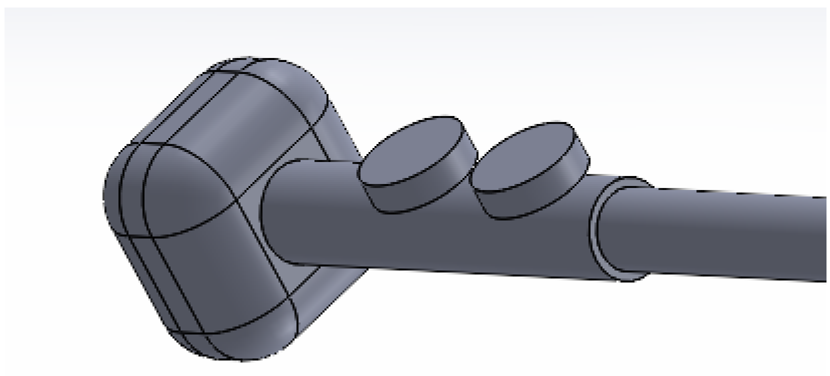


Figure 13: Device Handle. Contains an on/off button and a button to change the display color.

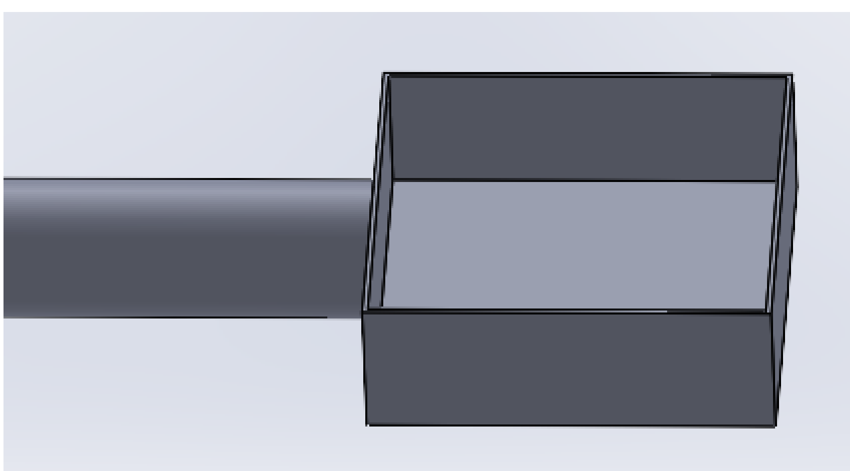


Figure 14: Visual display section of device with the LED display.

Fabrication

A. *Materials*

The Dynamic Balance Device is designed to be lightweight, durable, and comfortable for both the therapist and patient. This includes selecting materials that fulfill these requirements, but can still protect the embedded electronics and keep the device intact. The main section of the device will be constructed of a carbon fiber tube, thus protecting the interior electric components and wiring from friction and or impact. Carbon fiber was chosen for this material due to its low density of 1.7g/cm^3 [18]. The material for the handle will also be constructed of carbon fiber. Previous iterations of this device worked with the 3D printer plastic polyurethane, but this is where the previous design failed under loading. The exterior portions of the handle and display components will also be constructed with carbon fiber for its lightweight aspects and extremely high tensile strength of roughly 5,000 MPa [19].

The major electronic components will be an Arduino UNO board, a battery to power the Arduino, a rectangular LED board to display colors on, and various wires for connection points for the above electrical components [20]. The audio feedback portion of this device will be wired to the Arduino and powered through the same system.

B. *Methods*

The middle tube section of the device will be constructed with a 61 cm long, 0.8 cm external diameter, 0.7 cm internal diameter tube. On one end of the tube, there will be a 7.5 cm by 7.3 cm by 2.5 cm hollow rectangular prism attached to the tube with a hole near the connection point for wiring capabilities. The end of the carbon fiber tube will be attached to the center of one of the 2.5 cm by 7.3 cm faces, where the hole will be located. This is where the display will be labeled. One of the 7.5 cm by 7.3 cm faces will be removed and replaced with the display, allowing for easier access to the display.

The opposite opening end of the carbon fiber tube will be attached to the handle section, a 15.24 cm long by 1 cm outer diameter rod. This component will house two buttons that can turn the display at the end of the rod on or off. The counterweight will be connected to the opposite end of the handle and will function to manage the existing weight of the device, allowing the physician to more easily maintain the device in an upward position.

The electronic components of the device will be powered by a battery connected to an Arduino UNO, which will provide the proper signals to the circuitry. An LED board will be attached to the device in the rectangular box at the end of the tube. This LED will be attached with a display screen to properly show all colors that it can take on from the Arduino board. The wires that connect the buttons and the Arduino, display and battery will be run through the center of the carbon fiber tube. The speaker unit for the audio feedback will also be connected in this section.

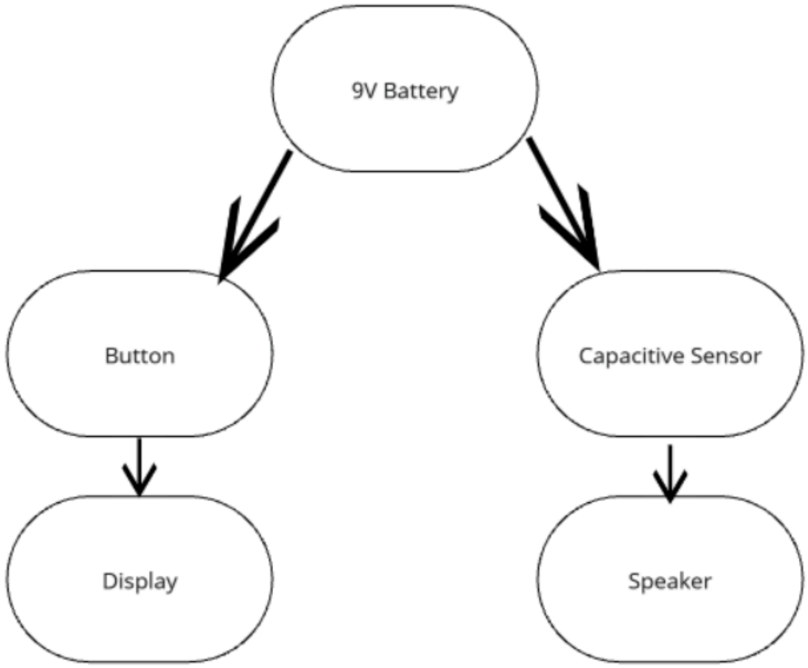


Figure 15: Flow Chart Diagram of the Electronic Components

Testing and Results

A. MTS Testing

The primary method of collecting quantitative data for the final device will be through MTS testing. The shaft material will be tested using a 3 point bending testing protocol, as shown in Figure 16. The elastic modulus and toughness will be calculated. These values will be compared to that of the previous prototypes in order to prove a statistically significant improvement in strength and durability. Additionally, testing will be performed on the 3D printed attachments, including the handle and display housing, as this was a failure point in the previous prototype.

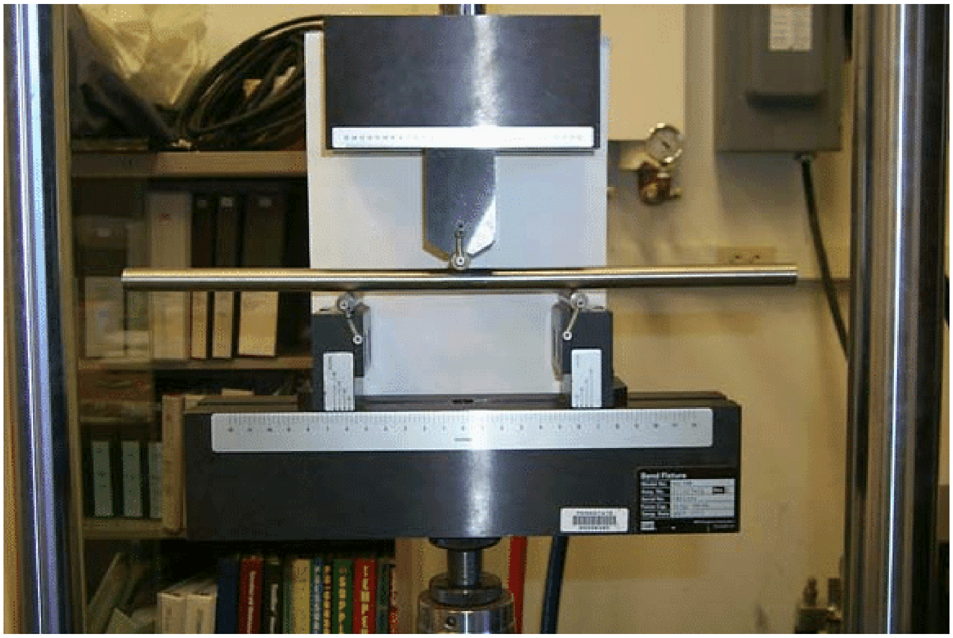


Figure 16: 3 point bending in an MTS machine [21]

B. Qualitative Testing

In order to gauge the user comfort of the device, a survey will be conducted. The participant will mimic normal usage of the balance device, as shown in Figures 17 and 18. This includes holding the device in front of the body with the arm extended for 15 minutes at a time. Participants will then complete a survey consisting of multiple questions on a 5 point scale in order to gain feedback on the weight distribution of the device, the counterweight action, and overall comfort of the handle design.

Figure 17, 18: Client using the balance device with a patient in order to measure their spatial awareness and depth perception (patient face redacted for privacy)

C. Battery Life Testing

With the addition of the auditory component, the battery life will likely decrease when compared to the last semester's prototype. The device will be turned on and used until the battery drains so that the client can be informed of how many hours of battery life can be expected based on typical usage.

Discussion

No results are currently available, as testing has not yet been conducted. Potential sources of error include biases of the participants of the qualitative testing, variations from the 3D printers and their infill density, and various assumptions made about typical usage patterns of the client. The device will accommodate varying colors, brightness, and volume, however, this still may not meet the needs of some patients. Additionally, the final prototype is being made for the needs of our client, which may vary from the needs of other physical therapists, especially considering that 70% of physical therapists are female [21]. Design changes will be made based on the results of the quantitative and qualitative testing results.

Conclusion

Approximately 30% of stroke survivors develop Spatial Neglect syndrome during their recovery [1]. This increases the patient's risk of falls and other injuries, slowing the recovery process. The client, a physical therapist specializing in neurorehabilitation, requires a dynamic device that can be used to assist patients in improving their sense of balance, depth perception, and spatial awareness. The final design combines a display with associated auditory feedback at the end of a graduated rod that is both lighter and more durable than previous prototypes. The design aims to increase user comfort and ergonomics when compared to the top-heavy prototypes of past semesters. Currently, only one prototype is to be created, however, should the need for more arise, the fabrication techniques and materials used shall be replicable. Future work includes improvements made to the display resolution, a more compact and portable design, and continued communication with the client on the performance of the final device.

References

[1] E. Esposito, G. Shekhtman, and P. Chen, “Prevalence of spatial neglect post-stroke: A systematic review,” Annals of Physical and Rehabilitation Medicine, vol. 64, no. 5, p. 101459, Sep. 2021, doi: https://doi.org/10.1016/j.rehab.2020.10.010.

[2] Centers for Disease Control and Prevention, “Older adult falls data,” *Older Adult Fall Prevention*, Oct. 28, 2024. https://www.cdc.gov/falls/data-research/index.html

[3] World Stroke Organization, “Impact of Stroke,” World Stroke Organization, 2025. https://www.world-stroke.org/world-stroke-day-campaign/about-stroke/impact-of-stroke

[3] E. Esposito, G. Shekhtman, and P. Chen, “Prevalence of spatial neglect post-stroke: A systematic review,” Annals of Physical and Rehabilitation Medicine, vol. 64, no. 5, p. 101459, Sep. 2021, doi: https://doi.org/10.1016/j.rehab.2020.10.010.

[4] K. Li and P. A. Malhotra, “Spatial Neglect,” Practical Neurology, vol. 15, no. 5, pp. 333–339, May 2015, doi: https://doi.org/10.1136/practneurol-2015-001115.

[5] A. Z. Durfee and A. E. Hillis, “Unilateral Spatial Neglect Recovery Poststroke,” Stroke, vol. 54, no. 1, pp. 10–19, Jan. 2023, doi: https://doi.org/10.1161/strokeaha.122.041710.

[6] “Bioness Integrated Therapy System Cost – Cost Digest,” Costdigest.org, Dec. 22, 2025. https://costdigest.org/bioness-integrated-therapy-system-cost/ (accessed Feb. 22, 2026).

[7] “Motion Works Physiotherapy & Sports Injury Centre,” Mwphysiostittsville.com, 2025. https://www.mwphysiostittsville.com/site/blog/2025/01/14/dizziness-vs-vertigo-treatment-for-vestibular-disorders (accessed Feb. 20, 2026).

[8] Y. Wang, L. Huang, Z. Wang, and T. Liu, “Visuomotor Training to Enhance Proprioception of Contralateral Wrist Based on the Cross‐Transfer Effect,” CNS Neuroscience & Therapeutics, vol. 31, no. 9, Sep. 2025, doi: https://doi.org/10.1111/cns.70504.

[9] Harris and P. A. Chouinard, “Mass distribution and shape influence the perceived weight of objects,” Attention, Perception, & Psychophysics, Sep. 2023, doi: https://doi.org/10.3758/s13414-023-02780-8.

[10] “What a Counterweight Does and Its Common Applications,” Biology Insights. Accessed: Feb. 25, 2026. [Online]. Available: https://biologyinsights.com/what-a-counterweight-does-and-its-common-applications/

[11] “Pair of 15mm Carbon Fiber Rods - 8",” Ikan. Accessed: Feb. 25, 2026. [Online]. Available: https://ikancorp.com/shop/rigs-matte-boxes-follow-focus/elements-rigs-rigs-matte-boxes-follow-focus-2/ikan-ele-15cfr8-p-pair-of-15mm-carbon-fiber-rods-8/

[12] “How Strong Is Carbon Fiber? Tensile Strength, Weight, and How It Stacks Up Against Steel,” Carbon Fiber Gear. Accessed: Feb. 25, 2026. [Online]. Available: https://carbonfibergear.com/blogs/carbonfiber/how-strong-is-carbon-fiber

[13] “Aluminum Round Bar Supplier | thyssenkrupp Materials NA,” Materials North America. Accessed: Feb. 25, 2026. [Online]. Available: https://www.thyssenkrupp-materials-na.com/materials/aluminum/round-bar

[14] “1/2 in. Sch 40 Furniture Grade PVC Pipe - White,” FORMUFIT. Accessed: Feb. 25, 2026. [Online]. Available: https://formufit.com/products/1-2-in-furniture-grade-schedule-40-pvc-pipe

[15] “How Strong is Aluminum? How Does it Compare to Steel?” Accessed: Feb. 25, 2026. [Online]. Available: https://www.gabrian.com/how-strong-is-aluminum/

[16] “Plastic Medical Tubing Materials,” Piedmont CMG. Accessed: Feb. 25, 2026. [Online]. Available: https://www.piedmontcmg.com/products/ivd-diagnostic-tubing-assembly/ivd-diagnostic-tubing-materials/

[17] H. K. Kondaveeti, N. K. Kumaravelu, S. D. Vanambathina, S. E. Mathe, and S. Vappangi, “A systematic literature review on prototyping with Arduino: Applications, challenges, advantages, and limitations,” *Computer Science Review*, vol. 40, no. 1574-0137, p. 100364, May 2021, doi: https://doi.org/10.1016/j.cosrev.2021.100364.

[18] SMITeam, “Carbon Fiber Cost: Factors That Influence The Most,” *SMI Composites*, Nov. 10, 2020. https://www.smicomposites.com/carbon-fiber-cost-factors-that-influence-the-most/

[19] Epsilon Composite, “The different grades of carbon fiber - Epsilon Composite,” *Epsilon Composite spécialisée dans la production de pièces et sous-ensembles en matériaux composites*, 2025. https://www.epsilon-composite.com/en/carbon-fiber-grades

[20] “Arduino Uno Rev3,” Arduino Online Shop. Accessed: Feb. 25, 2026. [Online]. Available: https://store-usa.arduino.cc/products/arduino-uno-rev3

[21] M. S. Lebold, M. W. Trethewey, K. Maynard, and D. J. Bieryla, “Technology Development for Shaft Crack Detection in Rotating Equipment,” EPRI International Maintenance Conference, Aug. 2003.

[22] “Physical therapist demographics in the United States - CareerExplorer.” Accessed: Feb. 21, 2026. [Online]. Available: https://www.careerexplorer.com/careers/physical-therapist/demographics/

Appendices

Appendix A: Product Design Specifications

Dynamic Balance Device

Product Design Specifications

BME 301

Lab 304

February 25, 2026

Client: Mr. Daniel Kutschera

Advisor: Professor Ohnsorg

University of Wisconsin-Madison

Department of Biomedical Engineering

Team:

Katherine Sattel (Team Leader)

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Function:

An estimated 30% of patients who have suffered from stroke experience Spatial Neglect Syndrome or lose vestibular sense, leading to falls that set back their recoveries [1]. Therefore, it is important that clinicians have devices that help patients practice balance and retrain neural networks so they can complete daily activities such as walking independently. However, existing devices don't allow the clinician to easily assist the patient because they are too heavy, or are not complex enough to effectively improve balance. The goal of this project is to design a lightweight device that allows the patient to practice scanning and complete a functional reaching test using an electronic component. As opposed to the previous design of an aluminum pipe with an LED, this device will be multifunctional and durable for convenient use.

Client requirements:

- The design is 10% lighter than the previous prototype (less than 0.32 kg)
- The prototype is durable and well constructed, especially where the electronic components attach
- Feedback elements, including auditory feedback
- At least a 56.25 cm^2 diameter display so that it is visible for patients with limited eyesight
- Varying colors and target shapes on the display
- A ruler integrated into the device so that a functional reaching test can be performed
- A reusable device that can be easily sanitized with a wipe

Design requirements:

1. **Physical and Operational Characteristics**
    a. **Performance requirements**:

        The final design must assist the physical therapist in improving visual scanning and postural balance for post-stroke patients suffering from spatial neglect syndrome. It must have a display at the end of the shaft that has the ability to present a variety of colors. The final design must be able to withstand frequent use, every weekday for up to 8 hours. The shaft must be a fixed length and durable while being a lightweight material that resists bending and deformation due to the load at the end of the shaft from the display.

    b. **Safety**:

        The final design must be a strong and durable material to ensure the device is stable and prevent failure while in use. This material must also be lightweight to prevent strain for the therapist and allow attention to be focused on patient care while using the device. The electronic elements must be safely enclosed to reduce risk of injury or hazards associated with exposed circuitry. The final design must also not include any sharp edges that could potentially harm the therapist while using the device.

c. **Accuracy and Reliability**:

The final design must accurately display the correct color when prompted by the therapist. The shaft of the device must have an accurate measurement system to ensure the provider collects reliable data when performing the functional reach test [2]. The final prototype must also reliably provide auditory feedback when the patient accurately completes the task.

d. **Life in Service**:

The final prototype must last at least one year with minimal servicing. The device will be used frequently for up to eight hours a day and five days a week. The handle and shaft of the prototype must be durable in order to avoid service within the first year. The electronics and circuitry may need quick maintenance, such as changing batteries, but these replacements must be simple and quick to perform.

e. **Shelf Life**:

The final device will be used exclusively indoors. The prototype must withstand frequent sterilization, as it must be wiped down between patients.

f. **Operating Environmen**t:

This device will be used in indoor environments for physical therapy. The device will be non-porous, as it will be cleaned and sterilized frequently. The device should be resistant to common deterioration and fluid corrosion. As the device will be used very frequently, it is important that it remains sturdy and can withstand normal forces from impacting the floor of the physical therapy spaces. Patients will be interacting with the device, so for preventative measures in case the patients hit the device against something, it may need additional force resisting properties along the base of the rod.

g. **Ergonomics**:

This device will be used by a physical therapist to assist in the rehabilitation process with a patient who has experienced a stroke. The device must be able to be held in one hand, easily held, and easily maintained for long periods of time, allowing the user to aid the patient if necessary. The colored target portion of the device should be easy to adjust and to have a control panel near the device's main interface near the handle.

h. **Size**:

The size of the rod should be a maximum of 1 meter in length. The display needs to be a target with at least a 7.5 cm diameter. The portion of the rod with measurements must be 61 cm long.

i. **Weight**:

The device needs to be under 0.32 kg with the majority of the weight located in the handle of the device to prevent fatigue for the patient while they are holding it up. The patient's perception of the weight is especially important, due to the higher torque load that comes with more weight allocated to the opposing end of the device.

j. **Materials**:

The materials for this device will need to be sterilized frequently, meaning they will need to be non-porous and able to undergo minimal maintenance without issue. The materials for the screen will need to be lightweight, waterproof, and have the ability to portray the main three primary colors, as per the interactive portion.

k. **Aesthetics, Appearance, and Finish**:

The device will have a professional and quality appearance. The device must be easy to clean and sterilized. The light up portion of the device must display various bright colors. The design will also include etched measurements along the rod, so the user and patient can both easily determine how far the patient can reach in any given condition.

2. **Production Characteristics**

a. **Quantity**:

There will be a total of one unit constructed for this project. More prototypes and development may be made in the future, but are outside the scope of this project.

b. **Target Product Cost**:

The target product cost will be within $500.

3. **Miscellaneous**
   a. **Standards and Specifications**:

      The final prototype must adhere to the regulations for a Class I medical device under FDA 21 C.F.R. Part 890 [3]. This device is classified as low-risk and therefore does not require any premarket approval by the FDA. The final prototype will contain electronic components and may be subject to IEC code 62353:2014 [4].

   b. **Customer**:

      The client is a doctor who specializes in neurological rehabilitation and physical therapy. The client intends to use the device daily, therefore, durability must be a priority. The previous prototype felt too heavy so lightweight material choices will be important. Additionally, the client will be using the device daily, for up to 8 hours per day, so it must be comfortable to hold for long periods of time. The device should appear more sleek and professional than the client's current set-up. The device must be intuitive to use and not have a steep learning curve.

   c. **Patient-related concerns**:

      The device does not need to be sterile but should be able to be easily cleaned with a wipe when necessary. The device must also be able to be used with one hand, allowing the physician to support the patient with the other, maximizing patient safety.

   d. **Competition**:

      Competition for this device includes the client's current solution, a 1 meter long PVC tube with a bright-colored laminated dot affixed to the end. This product is very rudimentary and was not intended to be a long-term solution. Additionally, a device currently on the market is the Bioness Integrated Therapy System [5]. This solution provides a variety of assessments for the patient as well as testing balance, reach, and their Romberg score. The client currently has this system in their clinic, however, this device is static and does not allow the patient to move while using it, limiting its efficacy in helping patients get back to performing daily tasks with ease and regaining full-body awareness.

References

[1] E. Esposito, G. Shekhtman, and P. Chen, “Prevalence of spatial neglect post-stroke: A systematic review,” Ann Phys Rehabil Med, vol. 64, no. 5, p. 101459, Sep. 2021, doi: 10.1016/j.rehab.2020.10.010.

[2] “The Functional Reach Test: Strategies, performance and the influence of age,” Annals of Physical and Rehabilitation Medicine, vol. 57, no. 6–7, pp. 452–464, Aug. 2014, doi: https://doi.org/10.1016/j.rehab.2014.03.003.

[3] C. for D. and R. Health, “Code of Federal Regulations (CFR),” FDA, Aug. 2023, Accessed: Feb. 01, 2026. [Online]. Available: https://www.fda.gov/medical-devices/overview-device-regulation/code-federal-regulations-cfr

[4] “IEC 62353:2014.” Accessed: Feb. 01, 2026. [Online]. Available: https://webstore.iec.ch/en/publication/6913

[5] “Therapies,” Bioness. Accessed: Feb. 01, 2026. [Online]. Available: https://bionessmedical.com/bits/therapies/

Appendix B: Proposed Expense Spreadsheet

Materials have not yet been purchased, however, the materials in the table below will be purchased when the project moves forward in its present state. More items will be added to this list over time, due to acquiring more materials from the University of Wisconsin-Madison's TEAMLab and other online vendors when needed.

Item	Description	Manufacturer	Mft Pt#	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total	Link
Structural Materials										
Carbon Fiber Tube	1m long, 8mm outer diameter, 7mm inner diameter carbon fiber tubing	CHZDPP	B0DJJTX3SQ	Amazon	B0DJJTX3SQ	2/22/2026	1	$54.25	$54.25	Amazon.com
Electronic Components										
Arduino Uno Rev3	Arduino microcontr-oller	Arduino	A000066	Arduino	7630049200050	2/23/2026	1	$27.60	$27.60	ArduinoStore.com
								TOTAL:	**$81.85**	
								Remaining Budget:	**$418.15**	

Table 4: Expense spreadsheet, showing existing expenses, materials, total amount spent, and the remaining budget.