Dynamic Balance Device

Preliminary Report
Biomedical Engineering Design 200/300
Department of Biomedical Engineering
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Abstract

Unilateral stroke neglect (USN) is a condition that affects the reaction to sensory stimuli and movement of the contralesional side of the body following a stroke. The client, Mr. Dan Kutschera, is a physical therapist that primarily works with USN patients to help them recover balance and range of motion. Static and dynamic balance therapies usually include visual scanning exercises, functional reach tests, or activities that combine dynamic exercises with visual scanning. The tool that the client currently uses to perform these exercises is a yardstick with a colored dot attached to the end. The functionality of this design allows the therapist to move the colored dot at different points in space for the patient to scan and reach for. These one-on-one exercises are performed with the therapist holding the device with one hand and stabilizing the patient with the other hand. Mr. Kutschera seeks a more professional and interactive design by displaying different colors and symbols rather than a single color. The balance device should be adjustable in length, have an electronic display on the end, and be lightweight and ergonomic for the therapist. Three design matrices were created during the research and design stage for the adjustable rod materials, the disk display electronics, and the handle controls. After analyzing the matrices, a final design was chosen, which includes a carbon fiber rod, LCD touchscreen display, and ribbed gym handle. For future work, plans have been created to order and obtain materials and begin fabrication of the device. Testing protocols will also be drafted throughout the prototyping process. By the end of the semester, a final prototype that meets the needs of the Product Design Specifications [see appendix A] and testing requirements will be presented to UW-Madison faculty, Mr. Dan Kutschera, and peers.

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Introduction

Motivation:

Every year, there are more than 795,000 new stroke cases in the United States. For stroke survivors 65 and older, a stroke leads to long term disability [1]. The probability of sustaining a stroke increases with age, but a stroke can occur at any age throughout life. Unilateral stroke neglect (USN), or spatial neglect syndrome, is a common symptom of stroke with a prevalence of 25-80% [2]. The percentage range is wide and varies depending on the type of neglect assessed and screening methods. Different types of USN screenings include but are not limited to: star cancellation, line bisection, copying, reading/writing, and behavioral. Star cancellation is the most common screening tool used, with a prevalence of 97.6% [3].

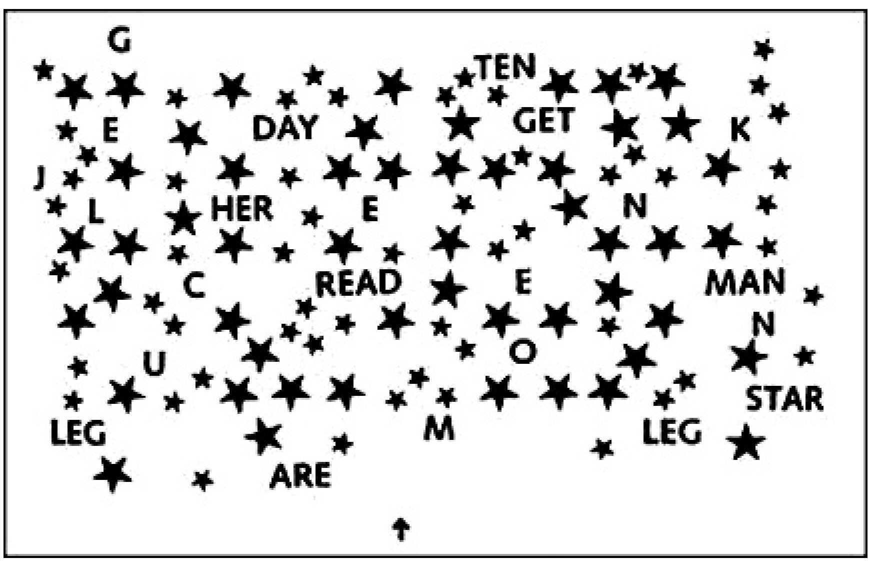


Figure 1: The Star Cancellation Test. Patients must cross out small stars (54 total), and the cutoff for USN positive is <44 stars [4].

Stroke neglect is defined by the unawareness of sensory stimuli on the contralesional side of the body. In general, this results in a lack of response to visual, tactile, auditory, and mental signals. Stroke survivors also can have aphasia, or difficulty understanding and responding to speech. USN can have detrimental effects to the quality of daily life. For example, USN sufferers often will only eat food on one side of the plate, bump into objects on their left side, or have an inability to access memories of visual stimuli on their left [5]. USN also leads to the degradation of motor skills on the contralesional side.The risk of injury increases significantly if steps are not taken to seek rehabilitation. During rehabilitation, patients might seek physical and occupational therapy to regain their sense of balance lost from USN.

The client, Mr. Dan Kutschera, is a physical therapist that primarily works with USN sufferers to regain their static and dynamic balance. Some examples of balance therapy include the functional reach test, static visual scanning, dynamic visual scanning, and dynamic reaching. The functional reach test is performed by extending an outstretched hand as far as possible while maintaining balance on a measuring tool such as a ruler. Scanning and reaching exercises involve identifying a colored dot or symbols at different points in space.

Figure 1: Functional reach test

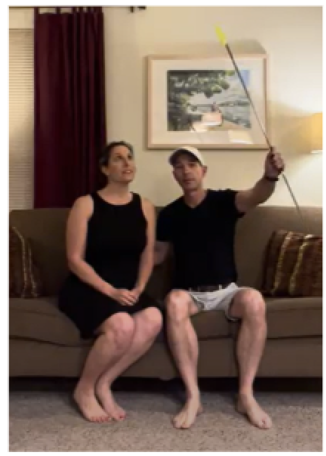


Figure 2: Static visual scanning

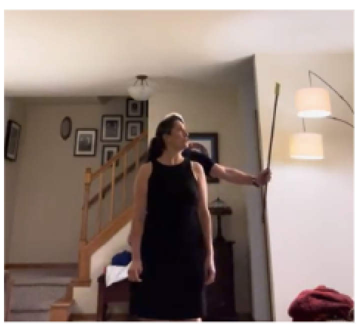


Figure 3: Dynamic visual scanning

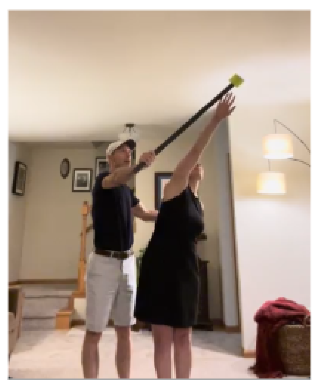


Figure 4: Dynamic scanning and reaching

Figure 2: Visualization of the functional reach test, static visual scanning, and dynamic scanning and reaching [Photos by Daniel Kutschera].

The device that Mr. Kutschera currently uses lacks professionalism and is limited to the single color of the dot attached to the end of the yardstick. The purpose of this project is to develop an interactive and professional device that assists in dynamic balance training by displaying various colors and symbols on the end, being adjustable in length, and being ergonomic for the therapist.

Our client sees patients with a wide range of ability, and thus a device should be applicable to multiple types of exercises. Designs that are multi-functional are favored over designs that perform only one exercise. Therefore, the device has to be able to perform exercises frequently used by the client such as the functional reach test, static scanning, dynamic scanning, and dynamic reaching.

Existing Devices:

The current device the client uses is a yard stick with a laminated dot attached to the end. There are a few limitations to this version, including a lack of professionality, inability to change the length of rod, and inability to change the color or shape of the dot. Overall, this limits the interactiveness of the device to engage the patient.

There are no other competing designs that apply to this application of balance therapy. However, there are existing devices for balance therapies that are commonly used on athletes and older adults.

The Biodex Balance System SD, as pictured in figure 3, utilizes a combination of scanning therapy as well as balancing on an unstable platform. The device can accurately perform the standard *Fall Risk Screening and Conditioning Programme* [6]. Handles are also provided to allow the user stability during exercise. The system costs anywhere between $782-5500. However, this system is not only costly but also does not apply in functionality to the one-on-one therapy sessions that our client is seeking to enhance with a handheld device. A more widespread and accessible device is required such that more clinics can implement an interactive and dynamic USN program.

Figure 3: Biodex Balance System SD [7]

Another competing design similar to that of the Biodex system is the Shuttle Balance Professional pictured in figure 4. The market value for the device is $1899.95. The Balance Professional involves an unstable platform suspended on chains that can increase in balance difficulty depending on the individual. The limitations for this device are also similar to Biodex in that it is a costly option and does not apply to the problem and limitations of the client's current method.

Figure 4: Shuttle Balance Professional [8]

There is no competing device that is specifically a handheld rod with digital display on the end that is designated for USN therapy. This project therefore has the opportunity to patent the design created over the course of the semester. Overall, the device will have to be cost effective as well as ergonomic for the therapist and patient in order for there to be a sizable market for it.

Background

Research:

Stroke neglect, otherwise known as spatial neglect, is a sensory unawareness of the contralesional side of the body following stroke. Most commonly, this occurs on the left side of the body. This can mean a lack of movement and response to tactile, audial, visual, and mental signals for the affected side. Some effects this can have on daily life include bumping into objects, only brushing half of the head, eating food on one side of the plate, or not responding to people on the affected side [9]. The left side is the more common side affected by stroke because the right hemisphere of the brain attends to both sides of the body whereas the left hemisphere only attends to the right side. If a lesion were to occur in the left hemisphere, the right hemisphere can compensate for the loss of control on the right side of the body. If the lesion occurred in the right hemisphere, there would be a noticeable loss of control of the left side of the body since the left hemisphere has no jurisdiction over that side of the body [5].

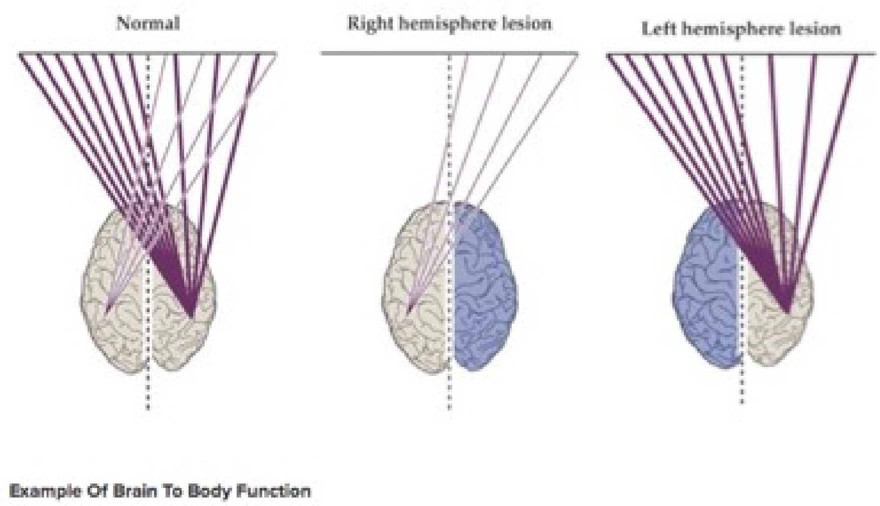


Figure 5: Effects of brain damage from stroke on brain activity by hemisphere [10]

Patients can also have aphasia, or difficulty speaking. Therefore, rehabilitation for USN should combine physical, occupational, and speech therapy. Physical therapy, specifically balance therapy, is recommended for all stroke patients. The regain of motor skills, range of motion, and balance is integral to decreasing the risk of injury [11]. Occupational therapists work with stroke survivors to adapt their home and work life to better accommodate their recovering condition. Speech therapists work with patients to regain skills lost in understanding and forming speech. The MicroTransponder Vivistim Paired VNS System was recently approved by the FDA and uses electrical stimulation of the vagus nerve to help patients that have more severe cases of loss of upper limb function [12]. Virtual reality or driving simulation tools are another up and coming method for USN visual scanning treatments.

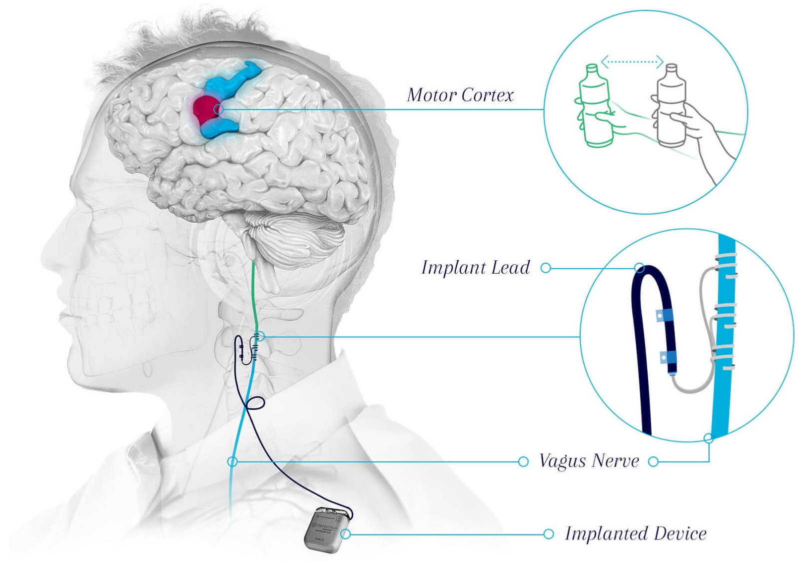


Figure 6: Vagus Nerve Stimulation System [13]

Treatments for USN include but are not limited to: visual scanning, vibration of neck muscles, prismatic glasses, movement therapy with physical constraints, eye patching, and trunk rotation [5]. Visual scanning treatments are the most effective rehabilitation practices for recovering from USN. The type of visual scanning the proposed device will target is navigation tasks. These tasks help the patient to scan for objects within the contralesional side of the body.

Design Specifications:

The dynamic balance device must meet specific requirements provided by the client. The device will be used often to assist physical therapists working with patients who have recently suffered from a stroke. The device must incorporate a retractable, telescoping rod that displays various symbols to target the functional reach test and aid the patient's static and dynamic stability. This includes a display disk that is sizable enough to provide the patient with a clear view of the symbols and a rod that can be adjusted to the client's requested length of two to three feet. The device will be used daily in a clinical setting and must resemble a professional medical device.

The device will be held in one hand, while the physical therapist supports the patient with the other hand. To make the device comfortable for the client to use consistently, the components of the device must be lightweight, and the electronics must be easily accessible. Therefore, the rod handle should include a lanyard and an ergonomic handle. Additionally, the rod, which must have a minimized weight, should also be easily size-adjustable with a telescoping design.

The device must also be consistently sterilized after each use, which occurs frequently throughout the day. This means the material used in the adjustable rod, display equipment, and electronics needs to be watertight and resistant to chemical breakdown. Additionally, the materials should be durable and have adequate tensile strength and a high strength-to-weight ratio. This ensures that the device will last in the event of a fall or other mishaps that may occur with daily use.

The electronics within the device display must be compact and any wires must be tucked within the rod or electronics box. The electronics should allow the display of various symbols or colors for the therapist to choose from. The device must also last throughout the entirety of a 40-hour work week. This will ensure that the device can be used with all patients without needing the battery to be changed.

Preliminary Designs

Adjustable Rod:

The first consideration that must be made is the material we will use to create the adjustable rod. The material must be lightweight, have strong tensile strength, and have a good strength-to-weight ratio. Three possible rod materials are discussed below.

1. Aluminum

The first proposed rod material is aluminum. The aluminum rod model would feature telescoping aluminum rods already available on the market with little additional fabrication needing to be done by the team. The rods would be hollow so any needed wiring can run down the length of the rod and a clamp at the center would allow the rod's length to be adjusted from the client's desired two to three feet.

Aluminum is a lightweight metal compared to its tensile strength with a density of 2.7 grams per cubic centimeter [14] and a tensile strength of 90-690 megapascals [14]. For the purposes of this device, an aluminum rod model would be adequately stress resistant though it is higher in weight than the other rod designs. As far as its ability to withstand frequent use of harsh chemical cleaners, aluminum can be known to experience some degradation of the surface, though should be able to resist degradation from more day to day sanitation methods. Telescoping aluminum rods range from about $10-30 [15], a cost safely within our budget.

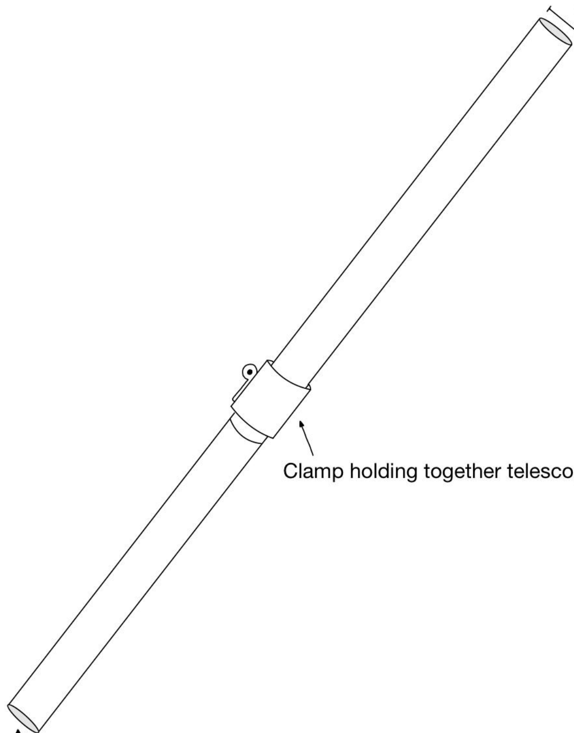


Figure 7: Depiction of telescoping aluminum rod [by Sarah Raubenstine]

2. Carbon Fiber

The second material proposed for the rod is carbon fiber. Two tubes would be fitted together in a telescoping manner in order to allow retractability between two and three feet, as per the client's request. Carbon fiber tubing ranges from $40-$60 [16], which is more than the other materials, yet still within budget. The tubing would be hollowed out to create a space for the electronics to fit inside and create a sleek outside look with no outer wiring. Additionally, all areas containing electronics would be sealed in order to keep the device watertight. This requires fabrication by the team.

The carbon fiber design is the most durable of the three materials. Carbon fiber has a very strong tensile strength of 2,500-7,000 megapascals [17]. Coupled with a density of 1.8 grams per centimeter cubed [18], carbon fiber is resistant to daily usage while maintaining a minimized weight. This ensures that the device can be comfortably used by therapists consistently throughout the day. Carbon fiber also has little to no reaction with chemical cleaners [19], allowing for therapists to sterilize the device often without any degradation. The team has decided to move forward with this design.

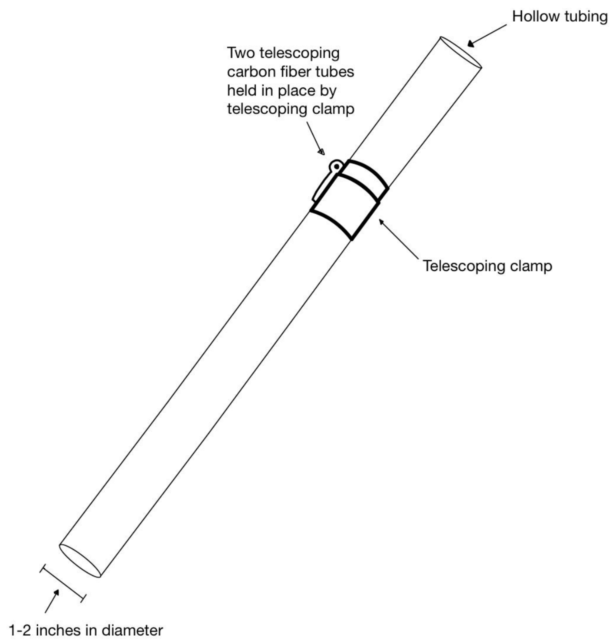


Figure 8: Depiction of telescoping carbon fiber rod model [by Sarah Raubenstine]

3. PVC Piping

PVC rigid plastic piping is the most inexpensive and readily available material. Ranging from $10-$20 for a considerable amount of tubing, PVC tubing can be bought at any hardware store [20]. The PVC tubing would be fitted in a telescoping manner, such as the other materials, however, fabrication would need to be done in order to create a rod ranging between two and three feet in length, as per the client's request.

The PVC piping model is the lightest design as PVC has a density of about 1.4 grams per cubic centimeter [26], ensuring the therapist would be able to hold the device for extended periods of time. However, this is also the least stress resistant design, PVC having a tensile strength of about 52 megapascals [26]. PVC can also be susceptible to surface degradation from frequent usage of harsh chemical cleaners [27] decreasing this model's ability to withstand the required sterilization between uses.

<u>Display Disk Electronics:</u>

1. 7-segment display and LED strip lights with IR remote

The first proposed design is a 7-segment display attached to the circular disk on the end of the adjustable rod. The display would be embedded within the disk, with the LED strip lights coiled around the display to provide the color element. This design requires the use of 2 IR remotes and 2 battery packs to be included in the design. 1 of the remotes would be paired with the LEDS, and the other remote is paired with the 7-segment display to control what numbers are displayed on the display. The 2 battery packs would be added to the back of the disk, which will add weight to the overall design. This is a potential pitfall, because if the overall device is extremely heavy then the therapist would not use the device as he intended to. Additionally, with 2 remotes, it makes it more difficult for a therapist to operate the device with only 1 hand, as the other hand must be supporting the patient. The 7-segment display is 1 in by 0.6 in in dimensions, so it is quite small. The display costs around $1 so it is very cheap to purchase. The LED strip lights would be purchased from Amazon and would cost around $20. Another aspect of this design is that the 7-segment display only displays numbers, and symbols and shapes cannot be programmed to be displayed as the electronics do not support that. The fabrication process for this design would be quite straightforward and wouldn't require extensive programming.

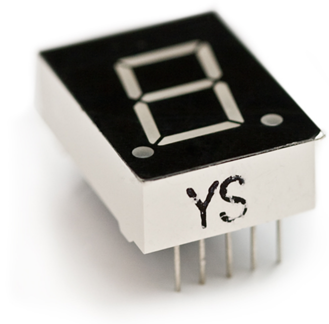


Figure 9: Image of 7-segment display [23]

2. LCD Touchscreen with clicker on handle

The second proposed model would utilize a LCD touchscreen that would be purchased from Waveshare. Additionally, the team would incorporate a clicker on the handle. The LCD touchscreen would need to be programmed using an Arduino. The clicker needs to be programmed to the touchscreen as well and needs to be a simple button. The LCD touchscreen is circular and is 1.28" in diameter. The client would be able to control the screen with his fingers, as the display is activated by touch. The team plans to implement several screens: one for selection of colors only or colors and symbols, one screen for actually displaying the colors/symbols. The clicker would allow the therapist to choose between only showing colors to the patient, or showing colors, symbols, numbers, and shapes. Once the therapist clicks a choice, what is displayed is randomized and the client controls when the new color or number appears on the screen. This LCD touchscreen requires the team to program using an Arduino. This would be the hardest to fabricate solely due to the complexity of the software programming. However, this design would be the cheapest to purchase, as the touchscreen is only $14.99 and the clicker would be around $1. The team has decided to move forward with this design, as it would satisfy the client's needs and requirements. This design would greatly improve on his existing device and help create a more professional mechanism for other physical therapists working with stroke neglect patients.

Figure 10: Image of LCD touchscreen display by Waveshare [22]

3. 8x8 LED matrix with IR remote

The third and final design is an 8x8 LED matrix display. This matrix display would be paired with an IR Remote as well. This display would be attached to the central disk as well. This design would be programmed using an Arduino as well as the other designs. The matrix can appear to be pixelated due to the placement of each pixel within the matrix. The matrix will allow for numbers, colors, and symbols to be programmed into the device. This matrix would be 2 in by 2 in, so it would be square in shape. The matrix is quite low in price and would be suitable for purchase, but would be more expensive than the LCD display. With this device, the fabrication would involve attaching a remote to the handle and a battery pack to the back of the disk. Although this device had good qualities, the LCD touchscreen outweighs this design as it accomplishes more criteria for the design matrix and helps the client achieve his needs for the product.

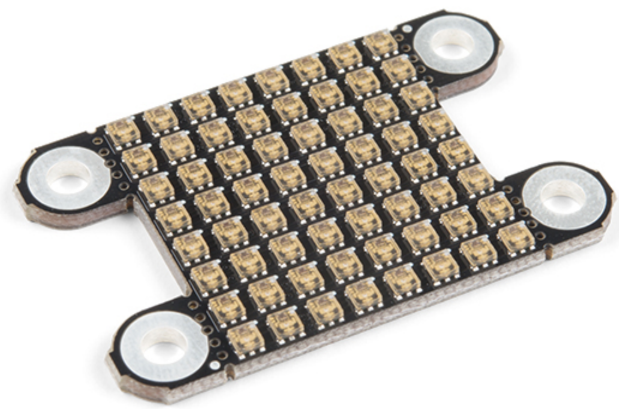


Figure 11: SparkFun 8x8 Lumini Matrix [23]

Handle Designs:

The handle designs are the different handles that attach to the rod where the user holds and controls the movement of the device from. It is also where the controls for the electronic disk will be located so that the user can change the displays while the device is in use. The handle will also be the attachment point for the wrist lanyard that the device will be hung by when not in use and attached to the user's wrist while in use.

1. Remote Control Case

The first design, The Remote Control Case, utilizes a basic rectangular prism design with fileted edges to increase user comfort. Its dimensions would be 5” (L) x 2” (W) x 1” (H) and would be printed in the Formlabs Form 2 or 3 with the intended material being Formlabs Flexible 80A resin. This resin produces stiff but flexible parts with a soft-touch finish [26]. The resin would be cured in fabrication and thus produce a water-tight product which is vital as the device would be constantly wiped down in use [26]. The design would be a solid piece that would be slid onto the rod through a hole at the top that does not extrude through the entire handle. It would also incorporate a loop at the base for a wrist lanyard. The design would include an optional cutout that would serve as a slot for an IR remote to reside in and be flush with the handle for user control.

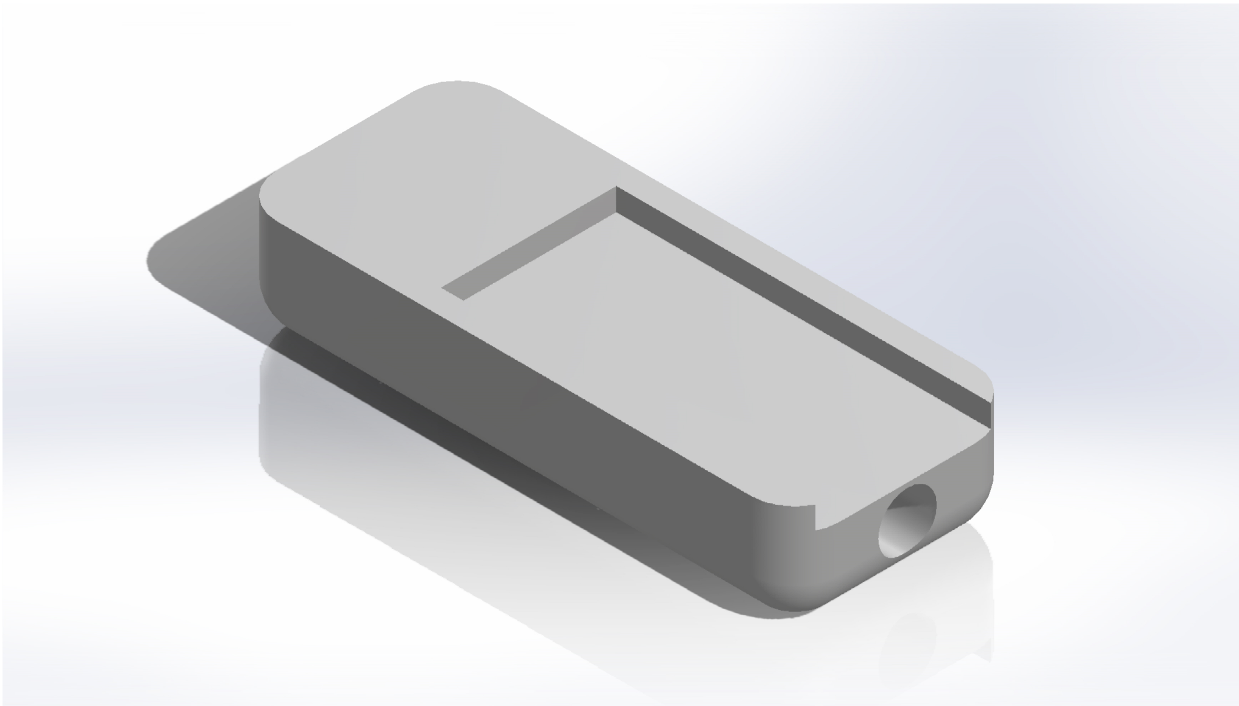


Figure 12: Remote Control Case SolidWorks drawing [by Gianna Inga]

2. Moldable Hand Grip

Design 2, The Moldable Hand Grip, involves creating a custom handle for the client, tailored to the exact curvature of their hands. Its material would be thermoplastic beads, which can be melted down in boiling water or a heat gun, molded into the intended product, and then hardened into a strong plastic. This design would require the client to come in and participate in fabrication as the handle would need to represent his hand's natural grip. In fabrication, the design would ideally be created for usage in both hands so the client would need to alternate between each hand to indent the material. The design would be the most ergonomic as the handle would exactly represent the clients hand placement and hold. If the handle would need to be altered or changed in any way, additional material would not need to be purchased as the thermoplastic beads are reheatable and reformable.

3. Ribbed Gym Handle

Design 3, the ribbed gym handle incorporates the idea of current, common usage of covers for the handles of the gym instruments for physical training. The material consists of vinyl plastic which are advantageous for withstanding heavy weights and high durability. It is also shaped to fit the contours of the human's hand and its already built-in ergonomic grips provide a firm grasp for long use for the client to perform the test on the patients. This ergonomic design especially reduces the strain and discomfort during prolonged use, which allows the client to perform the test more effectively. It does not involve the process of fabrication due to the design itself already in form after completing the purchase from the store, McMaster-Carr [27]. A secure grip can also minimize the risk of slipping or possible accidents during the test. This is a crucial factor since the participants are the client and the patients with stroke neglect syndrome which means that safety is the top priority while the balance training is in progress. A textured, ribbed surface provides additional grip and traction during its usage that involves versatility of motions such as lifting, moving sideways, rotating, etc. It is also easy to clean and maintain, promoting hygiene, which provides further advantage for the environment where the testing is repeated continuously with multiple sessions with one patient. Overall, the ribbed gym handle is an optimal design choice for performing functional target reach tests due to their superior grip, safety features, ergonomic design, durability, versatility, and ease of maintenance for hygiene. These handles enhance the overall performance with ensuring reliability and user's safety as well as comfort.

Preliminary Design Evaluation

Preliminary Design Route:

The final deliverable product was discussed with the client, Mr. Kutschera, given the one semester timeline. The final product must achieve the main requirements including professionalism and the specifications outlined in the Product Design Specifications [see Appendix A]. The purpose of the device is to help patients with neglect syndrome regain their balances. We team will move forward with the three main components: the handle, the rod, and the electronics display. Specifically, the team will pursue the carbon fiber rod, the gym equipment handle, and the LCD touchscreen display. Criteria for each design component are shown below.

Design Matrices:

1. ***Adjustable Rod***

Criteria (Weight)	Aluminum	Carbon Fiber	PVC Plastic

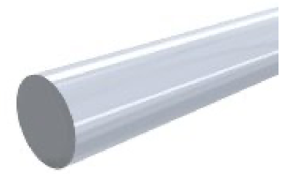
						
Weight (30%)	3/5	18%	4/5	24%	5/5	30%
Durability/Tensile Strength (25%)	3/5	15%	5/5	25%	2/5	10%
Sterilizability (20%)	3/5	12%	5/5	20%	3/5	12%
Cost (15%)	4/5	12%	2/5	6%	5/5	15%
Ease of Fabrication (10%)	5/5	10%	2/5	4%	2/5	4%
Total		**67%**		**79%**		**71%**

Figure 1: Preliminary design matrix of adjustable rod materials.

Weight of Material: Considers the weight of the given material. The client requested a lightweight rod for the device as they will need to hold it for extended periods of time with one hand, the other hand supporting the patient. The weight of the rod is weighted at 30% as it is directly tied to the device's usability.

Durability/Tensile Strength: Determines the amount of stress that a material can endure prior to breaking. The client requested that the device be able to be used for daily reach testing. A reach test determines how far a patient can reach without losing balance. Additionally, the client must be cautious of the patient's safety during these tests. For these reasons, the material of the rod must be able to withstand frequent use, a fall onto the floor or the weight of a patient grabbing onto it. This factor was weighted substantially high at around 25% to ensure the device is long-lasting.

Sterilizability of Material: Assesses the materials compatibility with common chemical sterilants. Being used within a hospital setting, the device will have to be sterilized frequently in between patients. Most likely a bleach or alcohol based cleaner will be used to clean the material. Different materials interact differently with cleaning solutions, as ease of sterilizability is important to this device, this is weighted considerably high at 20%.

Cost of Materials: Evaluates the cost of each material in comparison to the total budget of $300 given by the client. This was given a weight of 15% in the matrix because the materials range a considerable amount in price depending on how much is needed during the fabrication process.

Ease of Fabrication: Gauges the ease of construction for the team to put together the rod. If the material is only available in more rudimentary forms, it will require the team more effort to fabricate the final product. Some materials are available in forms closer to our final product, already in the form of collapsable or telescoping rods. Because the team is willing to construct what is needed for the different materials, this was weighted with the least importance at 10%.

Material 1: Aluminum

Aluminum was ranked lowest in the design matrix regarding the *Weight of Material*. Having a density of about 2.7 grams [40] per cubic centimeter, an aluminum rod would be the heaviest material choice out of the three designs. The weight of the rod is critical to the device as it will be used by our client frequently throughout the day and held with only one hand. If too heavy, the device will not only be harder to use and hold up, but will also not be able to be used for more extended periods of time. Constraining the device usage to the endurance of the client would represent a failure in the product design as this device is to be used for extended periods of time throughout the day.

Aluminum was ranked in the middle for *Durability/Tensile Strength*, though more susceptible to stress than carbon fiber, it is more resistant than PVC. Aluminum and its alloys can range between 90-690 megapascals [16], still being a dependable material to use in this sense, likely to maintain its shape and resist deformation with use. As the device is to be used regularly throughout the day, the resilience of the material is crucial to its longevity.

As for the *Sterilizability* of aluminum, the material was ranked in the middle because some high concentration alcohol solutions can cause minor degradation or discoloration of the metal under certain high stress conditions [41]. However, in the application of our device, the room temperature diluted alcohol cleaners most likely used by the client, should not be strong enough to cause a major impact to the efficacy and durability of the product. The sterilizability of the material is crucial because the device will be cleaned thoroughly between patients, so its resistance to commonplace hospital cleaners is important.

The *Cost* of aluminum is ranked in the middle, having a lesser price point than carbon fiber but a slightly higher price point than PVC. The price range of telescoping aluminum rods reasonable for our device range from $10-$30 [15], being well within the budget of our device.

Aluminum was ranked highest for *Ease of Fabrication* due to the large availability of telescoping aluminum rods already on the market [15]. Some of these rods are able to be found with measurements for the functional reach test already on the rod as well. These readily available rods would require no further work from the team to manufacture the rod element of the device, saving time, effort, and ultimately cost as well due to no needed supplemental materials. It should be noted that although the ease of fabrication is high for this material, the lack of construction by the team eliminates any flexibility that comes with manufacturing the rod and could impact the rod's compatibility with the other elements of the device's design.

Material 2: Carbon Fiber

Carbon fiber ranked in the middle for the *Weight* category compared to the other materials within the matrix. This is largely due to the densities of each material, with carbon fiber coming in at around 1.8 grams per centimeter cubed[18]. This is less dense than aluminum but more dense than PVC plastics. Despite this, the density is still considered fairly low and carbon fiber would make for an overall lightweight material that can be held in one hand for considerable periods of time. In the fabrication process, the thickness and depth of the rod components is subject to change, and carbon fiber can be shaped to achieve a usable, light rod to be incorporated in the Dynamic Balance Device.

Of all the materials, carbon fiber ranked the highest within the design matrix. In particular, carbon fiber received a perfect score in *Durability/Tensile Strength*. With a tensile strength rating of between 2,500-7,000 megapascals [19], it is well known as being a strong, dependable material. This makes it likely to last in the event of a fall or other incidents that can occur with consistent clinical use. In addition, it is very heat resistant and unlikely to deform in most storage spaces. This makes carbon fiber an ideal candidate for the Dynamic Balance Device.

Another strength of carbon fiber is its resistance to chemical abrasion. For this reason, carbon fiber scored perfectly in the *Sterilizability* category within the design matrix. Rubbing alcohol, or isopropyl alcohol, is often used as a cleaner for carbon fiber with little to no breakdown in the structure over time [19]. It is best to avoid using oxidizing agents when cleaning carbon fiber, such as hydrogen peroxide [34], however, the material is resistant to all other common cleaners. Additionally, carbon fiber is water waterproof and is often used in outdoor equipment, such as bicycles, which can be subjected to harsh environments. The material would most definitely withstand frequent cleaning with any water or alcohol based solutions.

The *Cost* ranking of carbon fiber scored the lowest among the materials. On the market, carbon fiber tubing ranges from $30-$60 [16]. This is considerably more expensive than both aluminum and PVC plastic, yet is still doable in the budget of $300. Additionally, due to the fabrication process necessary to create a retractable rod, multiple orders of tubing may be required. This scenario would raise the cost by a considerable amount.

For the *Ease of Fabrication* category of the design matrix, carbon fiber tied with PVC plastic, receiving a low score. Currently, there are no retractable carbon fiber rod designs on the market. In order to be used in the device, the carbon fiber would need to be fitted together into a retractable, sliding rod model in order to achieve the client's length specification of 2-3 feet. This requires multiple fabrication steps, fittings and measurements. However, this also allows for the incorporation of any measurement modifications given by the client or needed to incorporate certain electronic components within the device.

Material 3: PVC Plastic

PVC Plastic was ranked highest regarding the *Weight* of material, having the lowest density of the three options at a measurement of about 1.4 grams per cubic centimeter [42]. This lightweight design would allow for the client to use the device for extended periods of time without tiring, a critical request from the client. Though the specifications of rod thickness are not yet solidified, a PVC rod base for the product would yield the most lightweight design adding greatly to the practicality of the Dynamic Balance Device.

In terms of *Durability/Tensile Strength*, PVC plastic ranked the lowest among the materials. Although it has a considerably high impact strength [6], the tensile strength rating of PVC plastic is considered to be around 52 megapascals at twenty degrees celsius [29], or room temperature, and decreases in tensile strength with the addition of heat. The material is also less rigid than the other materials and subject to deforming with consistent pressure. These downfalls in structural integrity of PVC plastic make it a questionable material choice to be used for frequent clinical use.

PVC plastic tied for last in the *Sterilizability* category within the matrix. Most PVC plastics can handle various alcohol based cleaners, however, it is very important to avoid any abrasive cleaning solutions [30]. Additionally, with frequent scrubbing or wiping down, the outer surface is known to become increasingly matte as the outer finish degrades [30]. The client specified that the device requires constant cleaning throughout the day, which would slowly eat away at the outer layer of the PVC plastic rod, impacting the durability of the device.

PVC Plastic is very affordable, even in large quantities, and ranked the highest among the materials in the *Cost* category. Tubing ranges anywhere from $10-$20 for rigid PVC plastic and is sold at a variety of popular stores [20]. The adjustable rod using PVC plastic would need to be a custom design, and ordering the material in bulk would be very doable within the $300 budget. This would allow for easy adjustments and modifications throughout the fabrication process.

As for *Ease of Fabrication*, PVC was ranked the same as carbon fiber, both materials requiring further fabrication after purchase of the material. Currently on the market, no retractable PVC rods were accessible, requiring extra work from the team to construct a collapsible rod of PVC. Just as with carbon fiber the PVC would have to be fabricated into a sliding rod model fitting the client's specifications. Though requiring additional effort, it should be noted that this does allow for additional flexibility to meet specifications and allow compatibility with the other elements of the device.

2. *Disk Display Electronics*

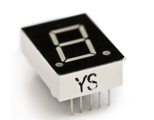
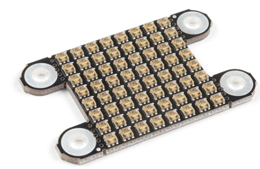
Criteria (Weight)	7-segment display and LED string lights (2 IR remotes)  		LCD touchscreen display (single button) 		8x8 LED matrix (1 IR remote) 	
Therapist Usability (Control Complexity and Weight) (25%)	2/5	10%	5/5	25%	4/5	20%
Patient Visibility (25%)	3/5	15%	5/5	25%	4/5	20%
Ease of Fabrication (Software and Hardware Complexity) (20%)	5/5	20%	2/5	8%	4/5	16%
Symbol and Color Variability (20%)	1/5	4%	5/5	20%	5/5	20%
Cost (10%)	3/5	6%	5/5	10%	4/5	8%
Total		**55%**		**88%**		**84%**

Figure 2: Preliminary design matrix of display electronics.

Therapist Usability (Control Complexity and Weight): Describes the ease of a licensed physical therapist (PT) to pick up this device and successfully use it with minimal to no training. Also combines weight specification as it determines the amount of time a therapist can use the device before tiring. PT usability was weighted at 25% because the ability to increase effectiveness of balance therapy was the most important functionality of the device.

Patient Visibility: Measures the ease in which to identify colors and numbers from the display with the naked eye. Given the target demographic for treatment with this device is patients aged 65+, the overall effectiveness of the device is tied to how well patients can react to the display. Thus this criteria was weighted equally with therapist usability at 25%.

Ease of Fabrication (Software and Hardware Complexity): Takes into account the scope of the semester, the skill levels and backgrounds of team members, and available documentation for each hardware and software option. Also considers the difficulty to program each option. Because the ease of fabrication directly affects the ability to produce a final prototype, this criteria was weighted relatively high at 20%.

Symbol and Color Variability: Considers the client request to have multiple color and symbol options for display. Design choices that have a greater opportunity for display variability are favored over other options. Since this design specification was requested by the client, this criteria was also given considerable weight at 20%.

Cost: Reviews the ability to develop each design option given a total budget of $300. This criteria was weighted lowest at 10% because the market value of every design option is well within budget.

Design 1: 7-segment display with LED string lights

All three electronics design options involve a 3D-printed disk that encases the circuitry and is attached to the end of the telescoping rod. Design 1 uses an Arduino-compatible 7-segment display [21] that will be paired with an Infrared (IR) remote. The LED string lights [44] will be coiled around the perimeter of the disk surrounding the numeric display and will also be associated with a separate IR remote. The disk will have holes in order to accommodate the battery packs for both electronic components as well as for the 7-segment display to be easily seen.

Design 1 was ranked lowest for *Therapist Usability* for two reasons. First, the design requires two remotes which cause the handle to be bulky and increase difficulty for the therapist to use the device with one hand. This design contains the implementation of 2 IR remotes, therefore the handle would have to accommodate both remotes in a way such that both remotes can be accessed easily with one hand, while maintaining a firm grip of the rod. This limitation presents a difficulty for the therapist, as the therapist must support the patient with one hand, while operating this device with another hand. The therapist would not be able to hold both remotes, nor control both at once. This issue would cause the therapist to waste more time, decreasing the overall efficiency of the product, and limiting the therapist's time with the patient. Second, design 1 is the bulkiest given two battery packs will be required for both components which requires the thickest disk to be 3D-printed, increasing the overall weight of the device. This design is bulky as it includes 2 battery packs, 2 IR remotes, and the LED lights, which will cause the therapist to feel that the device is heavy and cannot be used for long periods of time. This will reduce the overall productivity of the therapist, and reduce the effectiveness of the device.

Patient Visibility for design 1 was ranked middling due to the small nature of the 7-segment display qt a size of 1in x 0.6in [21]. The numeric display is the least visible out of all three design options given the much larger and much brighter LED lights surrounding the perimeter. The combination of the small display with the bright and vibrant LED lights can cause the patient to not be able to easily comprehend what is being displayed, and can cause other issues such as strained eyes and other difficulties. The LED lights may also be overpowering in the fact that the patient won't be able to see the number displayed on the 7-segment display. These limitations would prevent the patient from receiving the best care from the therapist and may prevent progress from recovering from stroke.

Ease of Fabrication for design 1 was ranked the highest amongst all three designs, because this design would require a simple assembly of the LED lights into a coil within the disk. The LED string lights will be purchased fully assembled by a third party source and will only require placement inside the disk to be fully functional as per the client requirements. The 7-segment display will require prototyping on a breadboard and programming in order to be paired with the respective IR remote. The IR remote control associated with the LEDs would already be paired with the LED lights, therefore no excessive software coding would be necessary for this design. These processes to assemble this device, both on software and hardware, would not be difficult for the team, as the team has experience in doing hardware fabrication and simple Arduino Uno code. However, there is documentation for hardware assembly, Arduino programs that are readily downloadable, and videos demonstrating pairing IR remotes to 7-segment displays available [46].

In regards to *Symbol and Color Variability,* all three design options have similar color display capabilities. All three designs have over 1 million choices in color selection, which leaves them equally ranked initially. However, design 1 requires the connection of the IR remote and this remote will limit the amount of possible colors that can be displayed by the amount of buttons. The remote contains around 10 buttons, hence there are only 10 colors that can be programmed into the remote. As for symbol variability, this design lacks this characteristic and therefore caused the overall score to decrease, as the 7-segment display is only able to present numeric values (0-9), and not any other symbols such as stars, circles, triangles. Due to these limitations, design 1 was ranked the lowest for Symbol and Color Variability.

Lastly, design 1 ranked the lowest for *Cost* because while the price for this design is well within budget, it is the most costly out of the three designs. This design would require the fabrication of three components: LED strip lights, 7-segment display, and 2 IR remotes, which individually don't cost much, but when combined, the total of the entire device is larger than those costs of the other designs. The combined cost of the LED strip lights, 7-segment display, and 2 IR remotes was $30.25.

Design 2: LCD touchscreen display

Design 2, the LCD touchscreen display, involves a circular touchscreen that will be embedded in the disk [47]. This touchscreen will be able to present 65K+ of colors and any sort of text can be programmed to be displayed. This design would not require a remote, and the therapist would be able to control what color/symbol is presented to the patient by simply touching the screen. The therapist would be able to slide between screens to choose colors or symbols. The display would be embedded in the disk in a way that can be easily removed so the display can be charged or battery can be replaced. The display would show a color that takes up the entire diameter (1.28 inch) of the display, so that the patient can clearly see the color. The display would show a number and symbol that can take up the entire size of the display. This device is also Arduino and RaspberryPi compatible.

For *Therapist Usability*, Design 2 ranks the highest with a score of 5/5. This design beats the other two designs mainly because there is no remote that is involved with this design. The therapist won't be needing to click buttons on a remote, rather they will be able to change the color at the tip of their fingers. They can configure what they would like to show the patient using their hands. In addition, the touchscreen display weighs significantly less than 1 pound, therefore the device will be lighter than the other designs. This minimal weight will help improve the experience for the therapist while using the device, thus improving the overall efficiency of the product.

This design ranked highly for *Patient Visibility* as well, as this display would allow the patient to see the most clearly. This display has 240x240 resolution, as it is a touchscreen. The other designs contain a 7-segment display and a 8x8 matrix, in which both can appear pixelated to the patient. In addition, the color, number, or symbol that is displayed on the touchscreen display will take up the entire size of the display, making it extremely accessible for patients to see what is displayed. It is important that these patients have the easiest display for them to look at, as they are aged 65 and above, and may face preexisting vision issues.

As for *Ease of Fabrication*, Design 2 scored the lowest among all three designs, because it would require the most time, effort, and learning in order to build this product. It does not require extensive hardware fabrication because there is no remote control associated with this design, and it would just involve embedding the screen into the broader disk. As for software fabrication, it will be difficult as we would need to code on an Arduino and need to implement several display screens. There is documentation available for the team to refer to when coding the necessary software [48]. There will be one screen for color selection, and one screen for number or symbol selection. Since it is a touchscreen display, it will require further software programming. The team has basic programming knowledge and skills, but have not coded a touchscreen display before. This design scored lowest, as it would require the most time to implement all software elements, and it might be a tight deadline given the timeline of the semester.

This design scored highest for *Symbol and Color Variability*. There are over 65,000 color selections for the therapist to incorporate into their testing. This design would allow a large selection of symbols, numbers, and shapes, as the therapist would simply have to touch to select which element to display on the screen. Due to the immense variability in color and symbols, this design won for this criteria category.

Cost category was quite similar for all three designs, however this design scored the highest. This design would only require the purchase of this touchscreen display that would cost $14.99 [22], and an Arduino to connect the code to the display. The team already owns a few Arduinos, therefore this item will not be calculated in total costs of all three designs.

Design 3: 8x8 LED matrix

Design 3, the 8x8 LED matrix, combines color and symbol display into one interface. Using an IR remote and programming, the matrix can display up to 16 million different colors and hundreds of numerical values and symbols [23]. Cutouts in the 3D-printed disk would accommodate the matrix and battery pack such that battery changes are easily accessible such that the LEDs can be seen and are flush with the rest of the disk.

Design 3 ranked on the higher end of *Therapist Usability* due to the matrix requiring only 1 IR remote attached to the handle. This design is already better than design 1 because design 3 uses 1 remote while design 1 uses 2 remotes. With one remote, the therapist will definitely have an easier experience using this device. This setup is ideal for therapists who are required to use the device with one hand, while supporting the patient with their other hand. Additionally, the size of the matrix is 2”x2” with a thickness of 0.75 mm [50] and one battery pack will be required, minimizing the overall weight and size of the device.

The matrix design was ranked higher for *Patient Visibility* than the 7-segment display due to the size of the matrix being slightly larger than the 7-segment display. However, the matrix did not rank as high as the LCD touchscreen due to its pixelated nature. Patients that have impaired eyesight might find it more difficult to distinguish pixelated symbols than on a LCD screen. It is important that the patient is able to see what is displayed on the matrix, otherwise the device has limited usability.

Design 3 ranked relatively high for *Ease of Fabrication*. This was due to the fact that only one IR remote would need to be paired to the system. There is also sample code and hardware setup guides readily available on the Sparkfun website [51]. In addition, there are videos demonstrating how to pair an IR remote to a 8x8 LED matrix with Arduino [52]. Because of these resources, the time spent learning how to use Arduino would be decreased drastically.

For *Symbol and Color Variability,* the matrix ranked highly because of the design's ability to display not only numbers but also hundreds of different symbols. These symbols, however, would be limited by the number of buttons on the IR remote. With a limited amount of buttons on the remote, this reduces the amount of possibilities of symbols and colors that the therapist can select from. The therapist would be limited to a maximum of 4-5 colors and 3-4 symbols. In addition, the remote may have arrows as buttons, which further reduce the number of viable buttons to program. Therefore, this is a drawback for the *Symbol and Color Variability* section, and hence caused this design to be ranked lower than design 2.

Design 3 ranked slightly higher than the 7-segment display but not as well as the LCD screen for *Cost* given that the market price of the matrix is $27.95. Along with the cost of the 8x8 matrix, the team would need to purchase a IR remote to connect to the matrix, which would further drive up the cost of the overall product.

3. ***Rod Handle***

Criteria (Weight)	**Remote Control Case** 		**Moldable Hand Grip** 		**Ribbed Gym Handle** 	
Grip & Control (35%)	2/5	14%	4/5	28%	4/5	28%
Ease of Fabrication (25%)	3/5	15%	3/5	15%	5/5	25%
Modifiable (20%)	5/5	20%	4/5	16%	2/5	8%

Durability (10%)	3/5	6%	3/5	6%	5/5	10%
Cost (10%)	2/5	4%	4/5	8%	4/5	8%
Total		**59%**		**73%**		**79%**

Figure 3: Preliminary design matrix of the rod control handle.

Grip & Control: Describes the ergonomics of the handle for comfort and efficiency. The device is held independently by one hand at a time but will be used interchangeably by both hands. Having a handle that is easier to grip is essential as the device will also be used by the client's non-dominant hand. Without a sturdy grip on the handle, the user would have decreased control of the device and it would be harder to manage its weight. To ensure a good grip and control of the device, the handle needs to have an ergonomic and non-slipping design, which is why this criteria is weighted 35%.

Ease of Fabrication (Software and Hardware Complexity): Depends on the design complexity, materials compatibility, availability of tools for manufacturing, applicable skills and background knowledge of the team members, and environmental considerations such as the availability of workspace. This criteria's weight is also determined by the actual procedure of designing and making it into a final product at the end of the semester. It was weighed relatively high due to its importance of incorporating various factors that can affect the overall design choice in terms of fabrication.

Modifiable: This takes into account the fact that the handle will need to be compatible with the rod and electronic design. It measures the ability of the handle design to be modified in order to securely attach to the rod as well as accommodate the electronic requirements. The most important compatibility is with the electronic design, as some designs utilize IR remotes that would need to be incorporated into the handle design per the client's request. Thus, it is important the handle design can be modified to collaborate with the other parts of the device and why it is weighted 20%.

Durability: Must take into consideration whether the handle will withstand continuous usage with the physical contact with a hand. It measures how long the material lasts without failures, collapses, and deformation. As a material designed for the purpose of holding, it must also be safe to sue without causing any injuries to the user. Furthermore, a higher score in durability can effectively reduce the matter of maintenance and avoid further inspection or repair. It should also be resilient to different ranges of temperature as the grasping of the handle for long duration can cause a temperature difference.

Cost: Assesses the cost to obtain or fabricate each design within the total budget of $300. This criteria is weighted 10% as the estimated cost of the handle designs are all under $50 with a median of $12.99[27][55].

Design 1: Remote Control Case

The Remote Control Case design utilizes the basic rectangular frame of a TV remote. Its dimensions would be 5” (L) x 2” (W) x 1” (H) and would be printed in the Formlabs Form 2 or 3. The intended material would be Formlabs Flexible 80A resin. The design would include a slot for the IR remote to be slid into if one is needed by the electronics design.

For *Grip & Control,* Design 1 ranked the lowest with a 2/5. This is because although the intended 3D printable material, Formlabs Flexible 80A, would increase some grip to the handle, the bulky and wide rectangular design would be difficult to properly grip and thus would decrease user control of the device.

Design 1 scored 3/5 in the *Ease of Fabrication* criteria. Fabrication would include creating the design in Solidworks and printing prototypes to ensure a sturdy grip can be made around the design as well as fitting the IR remote control so it is securely in place during usage and can come out if the batteries need changing.

The Remote Control Case was ranked the highest in the *Modifiable* criteria with a 5/5. This is because the remote case not only can be changed in SolidWorks to work with the dimensions of the rod but it is the design that accommodates a potential IR remote the easiest. Adding a remote to the other designs would be cumbersome and would affect the success of the user’s grip on it. In design 1, an IR remote would be able to be slid into a slot and would be flush with the surface not affecting the design.

For *Durability*, Design 1 scored lower with a 3/5. This is because of its wide ridgeless design. With a design that doesn’t promote grip, the force where a hand would hold the device would break down the handle over time with constant usage.

The remote control case design scored a 2/5 in the *Cost* criteria. This is because using the intended dimensions, which produce a volume of 163.9mL, and the cost of Formlabs Flexible 80A, $.29/mL, the approximate cost of the handle would be $47.53 to print[54]. This is an overestimation, as the design would have a hole to attach to the rod and potentially a slot for the IR remote. However, if we printed prototypes to test, the cost would be even higher.

Design 2: Moldable Hand Grip

Design 2, the moldable hand grip, involves using thermoplastic beads to create a custom handle for the client. Thermoplastic beads are a material that when heated up can be molded into any shape and when cooled, hardens into a strong plastic. The handle would replicate the client's exact hand grip as its design.

For *Grip & Control,* Design 2 ranks the highest with a 4/5 as it would be an exact mold of the client's hand grip. It would have a unique design and would offer the client a perfect grip and control of the device. It is the most ergonomic design, tailored exactly to the client. However, it is not 5/5 because the device will be held in both hands individually, and with this design, the handle would be exactly tailored to only one hand.

The moldable hand grip scored lower for *Ease of Fabrication* with a 3/5. This is due to the fact that fabrication would require the client to personally come in and hold the melted plastic beads to get an exact replica of their hand grip. Although the actual process of melting the beads and forming the model would be simple, setting up one to multiple sessions with the client if needed to recreate the handle would be difficult.

Design 2 scored fairly high in the *Modifiable* criteria with a 4/5. The design would be extremely modifiable as the beads can be reheated and reformed into different figures. As well as the fact that the design would either be able to directly mold the handle onto the rod or create a solid handle and drill a hole to fit onto the rod. However, including a remote for the electronics design would be difficult, as it would need to be indented in as well as have some velcro or some other attachment to keep it firmly on the handle. The remote also may disrupt the design of the handle and negatively affect grip and function.

For *Durability*, the moldable hand grip scored a 3/5. Although the thermoplastic beads harden to become a strong plastic, they can be reheated and lose their shape. It would be temperature sensitive and would fully remelt at 150ºF[55]. However, constant hand-holding and body heat may alter the design over time. Also since the design would only be tailored to one hand, holding it with the opposite hand would put pressure on ridges and also modify the design.

The moldable hand grip scored a 4/5 in the *Cost* criteria. In order to create this moldable hand grip, it would require the purchase of an 8oz bag of moldable thermoplastic beads. The cost of these beads would be $12.99[55], which is well within our budget.

Design 3: Ribbed Gym Handle

The ribbed gym handle design is inspired by the common, daily use of ribbed handles of the gym equipment for people to grab and apply force for their physical training. It is an ideal design choice for the handle with lack of slipping, capability of gripping, and further minor adjustment for the ergonomic design. This design choice can be achieved that can suit well with the other components of the device.

For *Grip & Control,* this design scored 4/5 because of its material texture, adaptability, and convenience in control for the user to perform functional reach tests while holding onto it with a single hand. It is suitable for the client to perform other tasks while holding onto the device with a convenient grip and not having to lose control. Its material additionally provide the benefits of comfort and safety for its users.

The *Ease of Fabrication* scored 5/5 due to the process of purchasing the product according to the necessary dimensions of the rod for the device. There is no further manufacturing or adjusting procedure involved with this design choice, which makes it more suitable with avoiding complexity. However, it may require further slight adjustments for having the rod inserted inside the hollow cylindrical project while considering exact fitting.

For the criteria, *Modifiable*, this design was scored ⅖, which is fairly low due to its limitation of changing the dimensions after the product is directly purchased with its shape in form. The seller of the product provides different options depending on the dimensions based on diameter. However, its shape cannot be modified afterwards in a large range to fit the design along with the other components of the device. Therefore, it would create a strict limitation for other components to fulfill the right dimensions according to the ribbed gym handle. The size of electronic components can possibly be limited due to the solid, round dimensions.

The *Durability* scored a maximum value for this material since vinyl plastic in a round grip structure is able to withstand the load being applied by a hand grasping around it. It will not have any rupture, split, or failure in any circumstances of using it as a handle for the purpose of functional reach test in dynamic balance training such as motions from lifting, moving sideways, etc. It may elongate depending on its coverage on other materials but not to an extent of cracking. Vinyl plastic is also known to have great insulation properties and it is an acceptable design choice for incorporating electronics inside it.

Based on the price set in packages listed in their site, the estimated *Cost* for the design is around $4.32 per piece. This cost is significantly below the maximum allowed budget and therefore it scored 5/5 for the cost criteria. Furthermore, the estimated weight of the design based on the cost for the product was calculated from the volume of a reference ribbed gym handle from CAD and converted using the density of vinyl (the expected material) [27][54]. The weight was 50.0g. However, the exact weight for the product ordered from McMaster-Carr is unknown and this is an estimation based on the given dimensions from their site.

Proposed Final Design:

After analyzing the design matrices for display electronics, adjustable rod materials, and handle controls, the team has decided to move forward with the LCD screen display, carbon fiber rod, and ribbed gym handle. The design will have to be modified to include a clicker toggle switch on the handle to control the LCD display. This was added to the design to increase usability for the therapist such that they do not have to touch the screen every time they would like to change a color or symbol. The team proposes to use a single button paired with software that randomizes the display of colors and symbols. The ribbed gym handle that is purchased from a third party source may need to be modified to accommodate these controls and to include a lanyard. The carbon fiber rod will also need further fabrication by the team. Overall, the designs chosen best fit the requirements of the client and maximize usability for both the therapist and the patient.

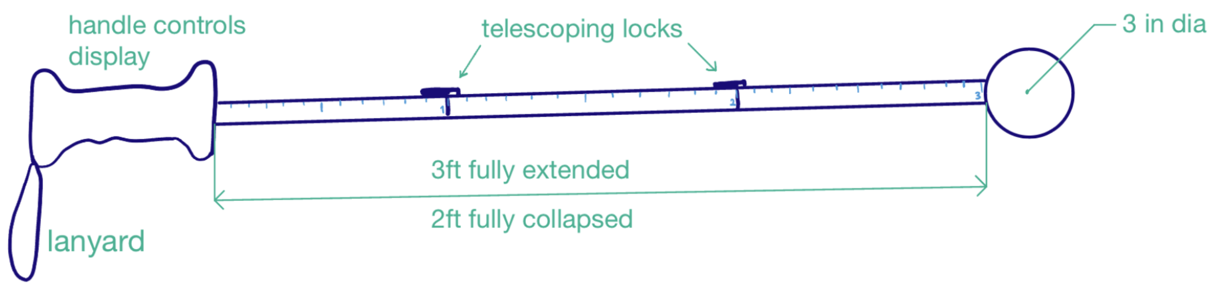


Figure 13: General design of device as per PDS [by Maggie LaRose]

Fabrication/Development Process

Materials:

- The telescoping rod will require two telescoping carbon fiber tubes, two feet and one foot in length. The tube larger in diameter must have an inner diameter that is at least 0.02 inches larger than the outer diameter of the smaller tube to allow for the telescoping mechanism.
- The telescoping rod also requires a telescoping tube clamp fitting onto the larger tube and an end stop fitting onto the smaller tube.
- The display electronics will require the purchase of the LCD touchscreen display, Raspberry Pi microcontroller, and circuit prototyping materials (wires, breadboards, toggle switch)
- The display disk will be fabricated with Ultimaker PLA

- The rod handle requires the purchase of the ribbed gym handle fit to the dimensions of the larger telescoping carbon fiber rod.

Methods:

- The rod tubing will be bought in two different diameters. Two tubes of different diameters will be cut into two rods that total three feet in length. The rods will then be fitted together to create a telescoping rod that is held in place by a clamp. Additionally, cuts in the rods will be made for wiring to pass through the tube. This can be fabricated in the TeamLab.
- The electronics components require programming and soldering that can be completed in the MakerSpace. The display will be attached to the rod using glue or an alternative adhesive. The wiring of the electronics will be placed within the rod. As for the power source, an additional 3D printed box made of polylactic acid can be fitted around the power source to keep it secure.
    - This requires a SOLIDWORKS file with the exact specifications of a box that can fit any battery/power packs, and can be attached to the telescoping rod.
- The handle grip will be stretched and fitted onto the end of the rod. A lanyard will then be attached to the handle.

Final Prototype:

To be updated at a later date.

Testing

To ensure the final prototype meets all the requirements of our client, there will be two test procedures to carry out. Our client, Mr. Dan Kutschera, and his other coworkers will be using this device consistently throughout their workday. They will be supporting the device with one hand and thus it is essential for the success of the product for the user to be able to hold the device with an extended arm for the duration of a rehabilitation exercise. The recommended post stroke rehabilitation session takes 45 minutes and from the videos of the client demonstrating the exercises, each exercise took approximately 30 seconds [28]. Therefore, keeping in mind that he was speeding up the exercises for demonstration purposes, the first test procedure is to hold the device with an outstretched arm for 1.5 minutes four times with 10-30 second break between each of the 1.5 minute intervals and record the time of failure if the tester did not reach the intended time or to rate the difficulty of the test. The tester will rate the difficulty on a scale of 1-10 (1 being not difficult and 10 being very difficult) This test needs to be repeated for both hands.

Mr. Dan Kutschera shared videos and descriptions of the intended usage of the device. This included quickly changing the position of the device, lengthening and shortening the rod, changing the colors and symbols displayed on the disk, and having the client touch the disk. So, the second test will be a mock exercise session. It will reenact a typical exercise session and will test all aspects that are required for successful usage. The user will first turn on and set up the disk display to show colors and attach the lanyard to their wrist. The user will rate on a scale of 1-10 (1 being not difficult and 10 being very difficult) how difficult it was to set up the device. Next, while holding the device with one hand and the rod set to the shortest length, the tester will quickly move the device to 10 different positions in space, changing the color with each different position. In each position, a "patient" will reach and lightly tap the disk. The user will rate how difficult it was to move the device around on a scale of 1-10. The device will be inspected for any damage or displacement of the disk due to the patient's contact and the device's motion. The success of color change and display will also be documented. Next, the user will lengthen the rod to the full length and rate the difficulty of the extension on a scale of 1-10. Then, the same test of 10 positions will be repeated with the extended rod. The two tests with different lengths will be repeated with the user's opposite hand. Finally, the last test will involve the user dropping the device and letting the lanyard attached to their wrist catch the device. Damage or displacement to the disk will be documented. The drop test will be repeated on both wrists.

Discussion and Future Work

Now that the prototype that is composed of the most favorable design choices for electronics, control rod, and handle are decided, the initial objective is to begin working on manufacturing the device. First, the appropriate amount of materials required and necessary tools for product specification for making the device will be determined according to proposed dimensions, size, weight, cost, and availability of resources. Then, the making of the prototype will be initiated through the use of Makerspace and TEAM lab provided by UW-Madison. Once the 3 different components of the device are established they will be merged in one piece. The aim for this stage of progress is by the end of November. After the prototype is finalized, multiple testings for the prototype's performance will be held with the client and be evaluated using all the criterias listed in the design matrix for verification on its functionality. This testing consists of four different training sessions that are specifically demonstrated by the client. If needed, further adjustments will be made based on the testing results and evaluations. The prototype will then be finalized by the ultimate deadline of this project which is the Poster Presentation session held on December 8th, 2023. Next semester, we anticipate discussing with the client about continuation and further development of the project and possibly implementing the device into actual use for the patients in need of dynamic balance training.

Conclusions

Currently, there are no existing devices that are specifically designed to perform the specific procedures of dynamic balance training that are discussed by our client. With the lack of competing designs, this prototype version of the device was modeled based on the criterias and functionalities that were optimized for the client to effectively perform PT rehabilitation exercises of stroke patients suffering from neglect syndrome. In order for the design to be viable in practical application, further testing and evaluation for the modifications on the specifications of the design may be required. Overall the device needs to be multifunctional that suits the client's performance with the patients that incorporates various static and dynamic movements. The main goal is to establish an optimal solution with a unique design that can feature both convenience and efficiency for continuous, daily usage.

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Appendix

A. PDS:

Function: Patients that have had a stroke and suffer from the subsequent stroke neglect syndrome have long-lasting symptoms including loss of awareness of one side of the body and aphasia (loss of ability to speak and interpret speech). Regaining static and dynamic balance is critical for reducing the risk of injury from falling. Our client, Dr. Dan Kutschera P.T., seeks to develop a device that improves upon the current method of dynamic balance training. Instead of a simple yard stick with a colored dot attached to the end, a more professional device with a telescoping rod and a light-up disk displaying multiple colors and symbols will be developed. The overall goal for the device is that it will be multifunctional across several therapies for patients recovering from stroke. These therapies include visual scanning training for regaining dynamic and static balance, speech therapy for patients with aphasia, and for performing functional reach tests.

Client requirements:

- Retractable, telescoping rod to aid in patients improving static and dynamic stability
- Must have a display disk of 3-inch diameter at the end of the telescoping rod to display shapes and colors to patients
- Device must measure distance for functional reach test and should have ability to change and sustain colors and shapes with a button control attached to the device itself
- Length of telescoping rod must be at a minimum 2 feet and a maximum of 3 feet; device must weigh 5 lbs or less
- Device must be easily storable, professionally built, and easily sanitized as it will be used everyday by physical therapists

Design requirements:

1. **Physical and Operational Characteristics**
    a. *Performance requirements:* The main performance requirement of this device is to assist physical therapists in helping patients regain static and dynamic balance to prevent falls after they have experienced a stroke. This device must improve upon the client's existing device of a yard stick with a colored dot at the end. The device will be a telescoping, retractable rod that displays measurements to target the functional reach test. There must be button controls on the handle to display colors and shapes on the end of the rod to aid with cognitive therapy. Additionally, the device must be resistant to wear from daily usage.
    b. *Safety:* The model will be constantly used throughout the day with several patients, so the device must have components intact and not cause any harm to users. The device will be lightweight and easy to carry around for the therapists. The device should maintain structural integrity and durability.

    c. *Accuracy and Reliability:* The device must accurately display measurements in inches and feet on the side of the rod in order for therapists to perform the functional reach test on patients. The rod must have at least one year long shelf life and should be reliable structurally and electronically, for the therapists to use everyday. The control on the device must reliably display the correct colors and shapes when therapists click on the corresponding buttons.

d. *Life in Service:* The device ideally should be functional for at least 1 year of use, given general repairs such as battery changes or replacing small parts (lanyard, IR remote, etc.). "Small" parts exclude parts integral to the basic design of the device, including the rod, handle, disk, and disk electronics. The device should be functional for constant use during the typical 40 hour work week (8 hour days for 5 days).
e. *Operating Environment:* The device will be entirely used indoors under standard room temperature (68-77 ℉ or 20-25 ℃) and pressure (1 atm) [1]. The device will be wiped down with medical-grade disinfectant in between uses and should thus be electronically water-sealed and erosion-proof from products containing 70% isopropyl alcohol [2]. The rod will be stored by being hung from the handle on a hook attached to a wall and should be resistant to wear and tear from repeated removal and replacement from storage hook between 20-50 times a day based on average number of appointments per day.
f. *Ergonomics:* The length of the rod should be able to be adjusted with two hands. The handle controls for lighting and display should be feasibly controlled with a single hand. A lanyard will be attached to the handle to increase the secureness of hold on the handle. The device should be able to be sanitized in its entirety in between uses.
g. *Size:* The size of this device should mimic that of a yardstick, with 3 feet being the maximum length and 2 feet being the minimum retractable length. The diameter of the retractable pole should be a maximum of 1 inch. To achieve adequate projection sizes, the display screen should be 3 inches in diameter.
h. *Weight:* The device should be able to be held in one hand for long periods of time without causing the therapist discomfort. The therapist will be supporting the patient with one hand, while the other hand will be holding on to the device. Therefore, the weight of the device should be kept to an absolute minimum, with a maximum 5 pounds.
i. *Materials:* Materials used should be lightweight, durable and waterproof. The telescoping rod should be made of a material with adequate tensile strength and a high strength to weight ratio, such as plastic or carbon fiber [3]. The display and display controls should have materials that are watertight, sterilizable, and enduring of daily use, such as lightweight metals or plastics.
j. *Aesthetics, Appearance, and Finish:* This device should resemble a professional medical device. It should look aesthetically clean with a waterproof model and sterilizable material. The light-up disk should be bright and any designs/numbers it projects should utilize the whole 3" diameter in order to be seen by the patient. The finish of the device should work as a customizable light-up target for patients to observe or reach for.

Production Characteristics

k. *Quantity:* One prototype of the model is all that is required for this project. More quantities can be established after the design model has been approved by the client and agreed to proceed further with practical usage for the rehabilitation center.

l. *Target Product Cost:* As of now, the goal for the total cost is set to be under $300. Considering the cost of materials, design specification, size dimensions, technical functionalities, and electronics, the estimated cost is ranging from $200 to $300. Currently, the client is managing two other BME design projects and the actual budget for the product also depends on two other groups' product cost which will be confirmed soon.

2. **Miscellaneous**

a. *Standards and Specifications:* There is no FDA approval required for devices aiding in physical therapy exercises and assessments. Specifically for this dynamic balance device, there are no specifications or federal regulations that would need to be followed in order to be produced.

b. *Training-related concerns:* There will be minimal training for the device because it will be created in a way that is intuitive for the client and other physical therapists. The people who will be working with the device are familiar with the proper usage of the device as they have been previously using a similar design. The device will be controlled by button(s) on the handle and the rod can be extended by unlatching locks and pulling.

c. *Competition:* Currently, there is a device named, Biodex Balance System SD [4] that is in practical use for patients and provides multiple features for static and dynamic balance training. It serves not only visual and auditory biofeedback for documentation that further specifies a patient's needs during the course of training. It is the only existing device that provides a fast, accurate fall risk screening and conditioning program. Although the program itself is easy to follow and does not require additional staff member's assistance, its capable features such as the reach test system along with customized analysis can be further simplified into a design that can be mobile, lightweight and controllable with a single hand. There are many other devices on the market used for the functional reach test, however these devices typically have a singular use and do not have the design flexibility to be used in other therapies as well.

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