Final Report: Dynamic Balance Device

Biomedical Engineering Design

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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 [1]. After experiencing a stroke, patients may experience difficulty in returning to their way of life that they were used to previously. Some of these life changes may include a loss of balance statically and dynamically, as well as a lack of cognitive skills. The client, Mr. Dan Kutschera, is a physical therapist who 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 areas 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 various colors. To achieve this goal, the team assembled an aluminum adjustable rod with an interactive and color-changing LCD screen attached to the end. The device was examined through a survey given to the client, usability weight testing, LCD screen visibility testing, and moment calculations. It was concluded that the device is professional and intuitive for therapist use. On the other hand, the weight and display size require modifications based on the results of testing. Overall, with the Dynamic Balance Device, the user can incorporate a durable, interactive, and cost-effective tool into the rehabilitation center to help patients improve their balance training.

I. Introduction

A. Motivation

The motivation for the Dynamic Balance device was to create a tool that can better engage and help patients with stroke neglect syndrome in a clinical physical therapy setting. The current methods of improving patient balance, reach, and scanning skills are either very expensive or are homemade and lack professionalism. The advancement in design will help the client engage his patients and improve their care, helping them to make greater strides in their rehabilitation journey.

The client, Mr. Dan Kutschera, is a physical therapist who 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.

Our client sees patients with a wide range of abilities, and thus a device that can be used for multiple types of exercises is essential. Multi-functional designs are favored over designs that perform only one exercise. Therefore, creating a device that is able to perform exercises frequently used by the client such as the functional reach test, static scanning, dynamic scanning, and dynamic reaching, can help the client be more efficient in assisting his patients in recovery.

B. Competition

There are not many competing models of this device on the market that exactly satisfy the client's goals and budget. The primary existing device is what the client currently utilizes at his practice, the current model of a meter stick with a colored dot attached to the end. This design is able to aid patients in performing the functional reach test and dynamic balance therapies, however, lacks the professionality that the client is looking for as well as the ability to change colors and display symbols on the end of the rod. The client would like to improve his existing design by creating a more professional device that implements a technological aspect to support the complexity of the client's requirements. Although, his existing design is a very cost-effective option averaging the client about $5 for materials.

Figure 1: Mr. Kutschera's current device and demonstration of static balance exercises.

Another competing device that differs in functionality though is similar in design to the resulting dynamic balance device, is the “selfie stick”. This device has a similar telescoping rod design with a button on the handle that can control a user's device on the end of the rod. However, this device is tailored to photography rather than the specific physical therapy practices that the client wishes to use the device for, not being able to perform the functional reach test or hold the desired display to perform dynamic balance and visual scanning training. The cost of selfie sticks range from about $20-$40 [2]. If the team were to implement a selfie stick to the device, there would need to be several additional fabrication methods and costs associated with the design. The team would have to incorporate a display component in addition to the selfie stick.

Figure 2: The “Selfie Stick” [2]

Lastly, a primary competitor is the *Bioness Integrated Therapy System (BITS)*. This is a more advanced device that provides a variety of interactive touchscreen activities for patients to improve coordination, reaction time, reach, and depth perception. However, this device requires the patient to stand in place in front of a large touch screen, not allowing these tests to take place along with movement. This device would not support the client’s requirement of the device being compatible with dynamic patient movements, as this device requires the patient to remain stationary. This device is also very expensive, costing PT practices upwards of $10,000 [3]. The client has expressed a niche in the market of dynamic balance therapy devices, desiring to create a device that accomplishes all that the BITS targets, while also supporting dynamic movements by the patient.

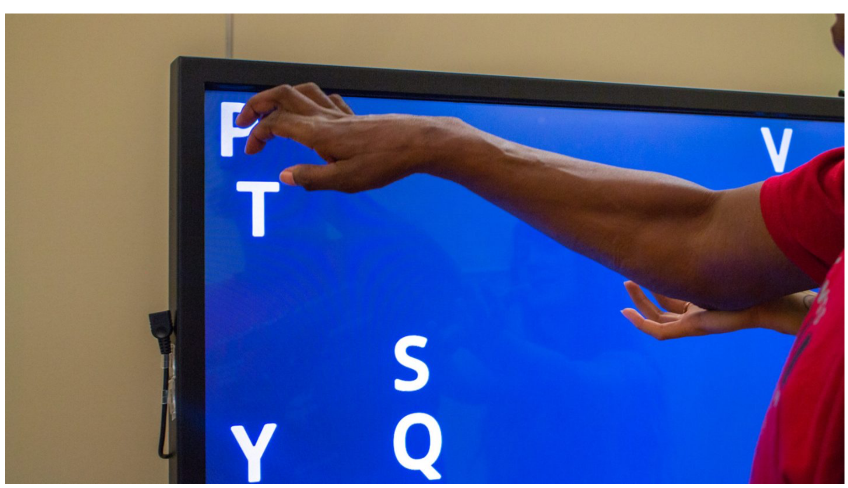


Figure 3: Bioness Integrated Therapy System [3]

C. Problem Statement

Stroke-surviving patients who suffer from the subsequent stroke neglect syndrome primarily lose awareness of one side of their body and experience long-term symptoms including loss or limited balance and cognitive skills. Physical therapy exercises aim to help patients regain static and dynamic balance and are critical to reducing the risk of severe injury from falling. The client, Mr. Dan Kutschera P.T., seeks a more professional device that improves upon his current method of dynamic balance training. Instead of a yardstick with a colored dot attached to the end, the client desires a telescoping rod supporting a light-up disk with the capacity to show multiple colors and symbols. This device must be able to serve multiple therapy exercises including static balance, dynamic balance with visual scanning, and functional reach tests.

II. Background

A. Information Regarding Unilateral Stroke Neglect (USN)

Every year, more than 795,000 people are affected by a stroke in the United States. The probability of having a stroke increases with age, and for stroke survivors 65 and older, a stroke often leads to long-term disability [4]. Unilateral stroke neglect (USN), or spatial neglect syndrome, is a common side effect of a recent stroke, with a prevalence of 25-80% among patients [5]. Different types of USN screenings include but are not limited to: star cancellation, line bisection, copying, reading/writing, and behavioral assessments. Line bisection has patients bisect lines on paper to the best of their abilities, diagnoses are based on how well patients can identify where to bisect the line. Copying reading and writing is similar, with diagnoses given based on the accuracy of the patient's attempt at copying. All methods diagnose USN with differing accuracy rates. Star Cancellation is the most commonly used screening tool, with a prevalence of 97.6% among patients [6]. Star Cancellation is depicted below in Figure 3; patients must cross out stars, and based on how many are missed, they can be diagnosed.

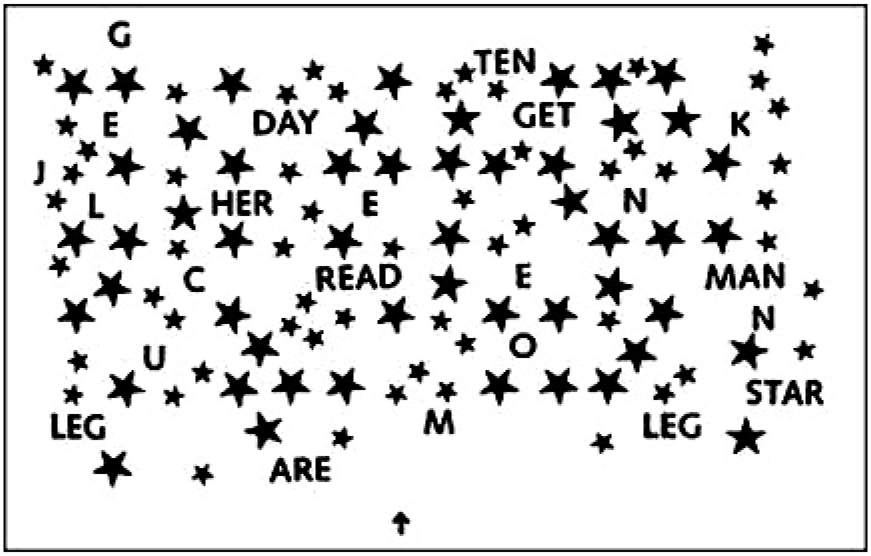


Figure 4: The Star Cancellation Test. Patients must cross out small stars (54 total), and the cutoff for USN positive is <44 stars [7]

The unawareness of sensory stimuli on the contralesional side of the body defines stroke neglect. In general, this results in a lack of response to visual, tactile, auditory, and mental signals. Stroke survivors can also suffer from aphasia. Aphasia is defined as the ability to understand or produce speech. For example, those affected may understand speech, but have trouble responding, emitting only short words that require great effort [8]. Overall, USN has detrimental effects on the quality of daily life. For example, USN sufferers often 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 [9]. USN also leads to the degradation of motor skills, such as standing, walking, reaching, or anything requiring movement of the body on the contralesional side. During rehabilitation, patients often seek physical and occupational therapy to regain their sense of balance lost from USN, and take steps to regain independence and quality of life.

The main treatment method for USN is rehabilitation via physical therapy. There are many methods of this, including but not limited to: visual scanning therapy, active limb activation, prism adaptation training, and sustained attention training [10]. Visual scanning treatment requires patients to scan for objects in space and identify them. Active limb therapy requires frequent movement of limbs on the affected side of the body. Sustained attention therapy has patients focus on objects in space for extended periods. Prism training is a therapy in which patients wear prisms over their eyes, which deviate the visual field entirely to the affected side [10]. While prism therapy is not very common, it requires very little intervention from the administrator and is largely movement-based [10]. Overall, therapy is the most effective treatment for USN, and is used worldwide.

B. The Importance of Balance Therapy in Rehabilitation

Balance Therapy is essential to improving the lives of Unilateral Stroke Neglect patients to reduce the risks of falling. By addressing balance deficits and increasing awareness on the neglected side, balance therapy plays a critical role in rehabilitation by enhancing mobility and functionality that contribute significantly to the patient's well-being and safety. The functional reach test measures the distance reached by a patient's outstretched arm maximizing their forward reach while maintaining balance. Patients able to reach greater distances and keep their balance are seen to have a lower risk of falling [11]. As seen in Figure 5, lesser reach distances are associated with a greater risk of falling than normal. By improving the patient's functional reach, balance is significantly improved and the patient's risk of injury from falling is reduced. As for static and dynamic balance therapies, they also help to engage the cerebrum, which controls balance and coordination [12]. This practice allows the brain to continuously recognize the affected half of the body [13]. Scanning exercises help to improve contralesional space exploration by engaging the occipital lobe and the recognition parts of the brain [12][13]. For example, patients are asked to visually scan and identify specific items or targets presented in their neglected field. Promoting exploration of the contralesional side by prompting patients to pay attention to target stimuli and consciously be aware of their neglected space has been strongly associated with an improvement in stroke neglect patient performance on paper and pencil testing to assess the severity of neglect [14]. Overall, physical therapy is essential for stroke-neglect patients in recreating the neural pathways that have been affected by a stroke [15]. By encouraging usage of their contralesional side, and relearning balance and coordination that had been lost, physical therapy has the capacity to dramatically increase the quality of life of stroke neglect patients. Patients can achieve healthier, fuller, more mobile lives through the repetition of these various exercises.

Measurement in inches	Interpretation
10" or greater	Low risk of falls
6" to 10"	Risk of falling is 2x greater than normal
6" or less	Risk of falling is 4x greater than normal
Unwilling to reach	Risk of falling is 8x greater than normal

Figure 5: Interpretation of functional reach test measurements. [16]

C. Client Information

The client, Mr. Dan Kutschera P.T., is a physical therapist working at Encompass Health in Fitchburg, Wisconsin. He is interested in creating a therapeutic device that assists patients with static balance, dynamic balance, visual scanning, and functional reach tests. Many of his patients are affected by USN, and through these therapies, Mr. Kutschera helps them regain essential functionality and balance needed for daily living.

D. Client Requirements

The client requested a more professional and technologically advanced device that enhanced their existing design. The base of the device must be a retractable, telescoping rod able to be adjusted between two to three feet in length, with measurements on the side of the rod to perform the functional reach test. There must be a disk display on the end of the rod capable of showing colors and common symbols clearly enough for patients to view from two to three feet away. The device will also be sterilized between uses frequently throughout the day, so any materials and electronics need to be resistant to degradation and water-tight. Additionally, the device will have a lanyard attached to the end of the rod, ensuring that the device can be easily stored by hanging the lanyard on the wall of the clinic. The price of materials and fabrication for this device should not exceed approximately $300 USD.

E. Design Specifications

The client tasked the team with fabricating a device used to assist physical therapists working with patients who suffer from stroke neglect syndrome. The device must have a retractable, telescoping rod with a display attached on the end. This disk must be capable of showing colors and symbols to use for reach and balance testing. This display disk needs to be large and bright enough to provide patients with a clear view of the colors or symbols on the screen. The visibility of the disk is especially important as patients suffering from stroke neglect are commonly over the age of 65 and may have trouble with their vision. This display on the end of the rod will be controlled by a button on the handle for clinicians to seamlessly change screen colors while working with patients.

The rod needs to be adjustable between two and three feet to best fit the needs of the patient. The physical therapist will hold the device in one hand and support the patient with the other. To ensure the comfort of the therapist, the disk and rod weight needs to be minimal to reduce the difficulty of holding up the device. Additionally, the side of the rod will show measurements that will aid in the functional reach test extending the length of the device.

The handle of the device should have an ergonomic design to eliminate any discomfort from frequent use. There will be a lanyard on the end of the device for easy hanging storage as well as for the safety of the device and the user.

The device must be able to withstand frequent sanitization, so any electronics within the disk must be watertight and sealed from the outside and the materials used for the rod and handle must not degrade or tarnish from repeated uses of common alcohol-based hospital disinfectants.

Materials and fabrication cost should not exceed $300. The full description of design specifications is located in *Appendix A: Product Design Specifications*.

III. Preliminary Designs

Adjustable Rod:

The first consideration that must be made is the material used 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 and a tensile strength of 90-690 megapascals [17]. 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 it should be able to resist degradation from more day-to-day sanitation methods [18]. Telescoping aluminum rods range from about $10-30 [19], a cost safely within the budget.

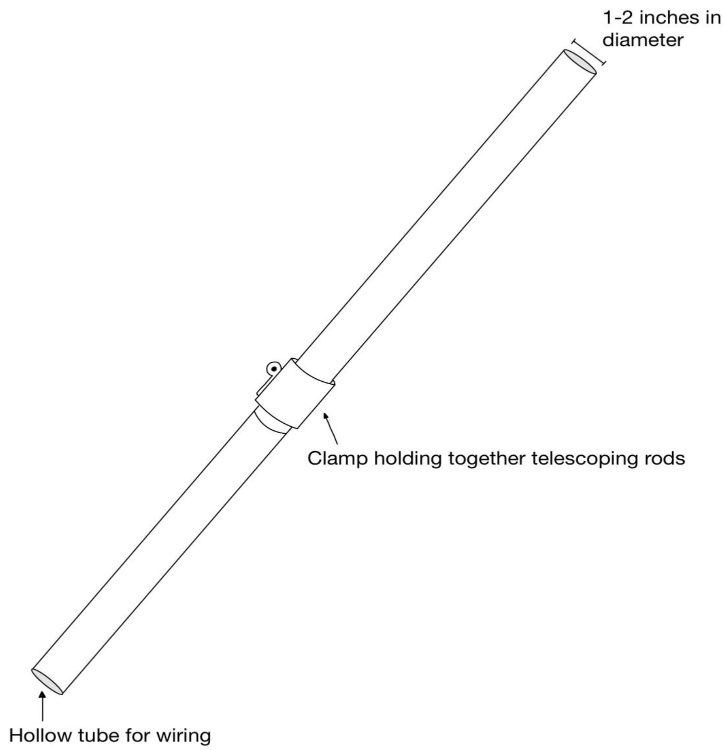


Figure 6: Depiction of telescoping aluminum rod [by Sarah Raubenstine]

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 [20], 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 [21]. Coupled with a density of 1.8 grams per centimeter cubed [22], 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 [23], allowing for therapists to sterilize the device often without any degradation. The team has decided to move forward with this design.

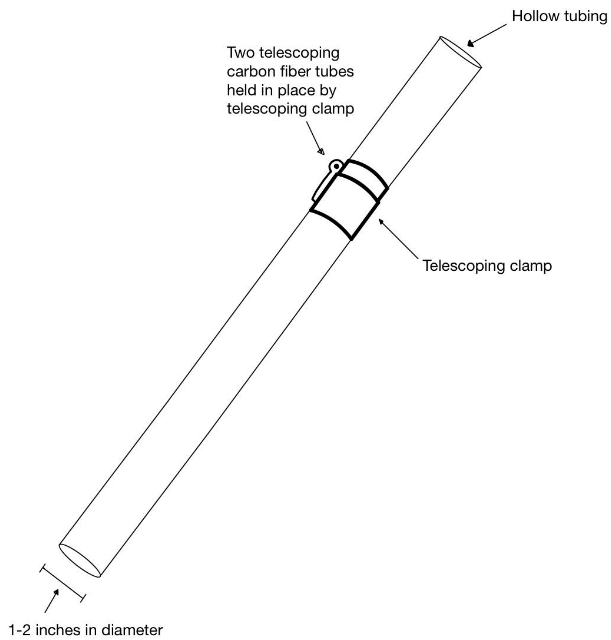


Figure 7: Depiction of telescoping carbon fiber rod model [by Sarah Raubenstine]

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 [24]. 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 [25], 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.

Display Disk Electronics:

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.

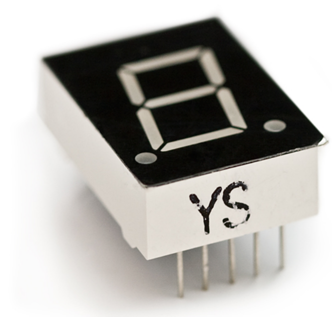


Figure 8: Image of 7-segment display [28]

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 9: Image of LCD touchscreen display by Waveshare [29]

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.

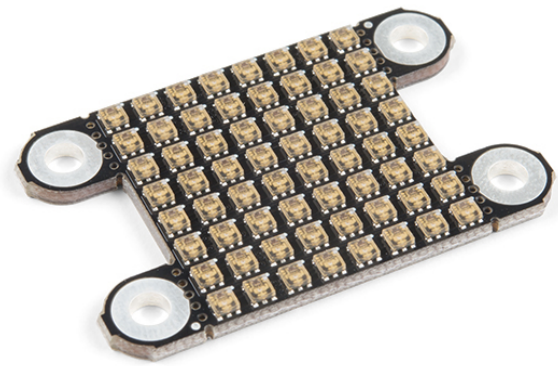


Figure 10: SparkFun 8x8 Lumini Matrix [30]

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 [31]. 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 [31]. 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.

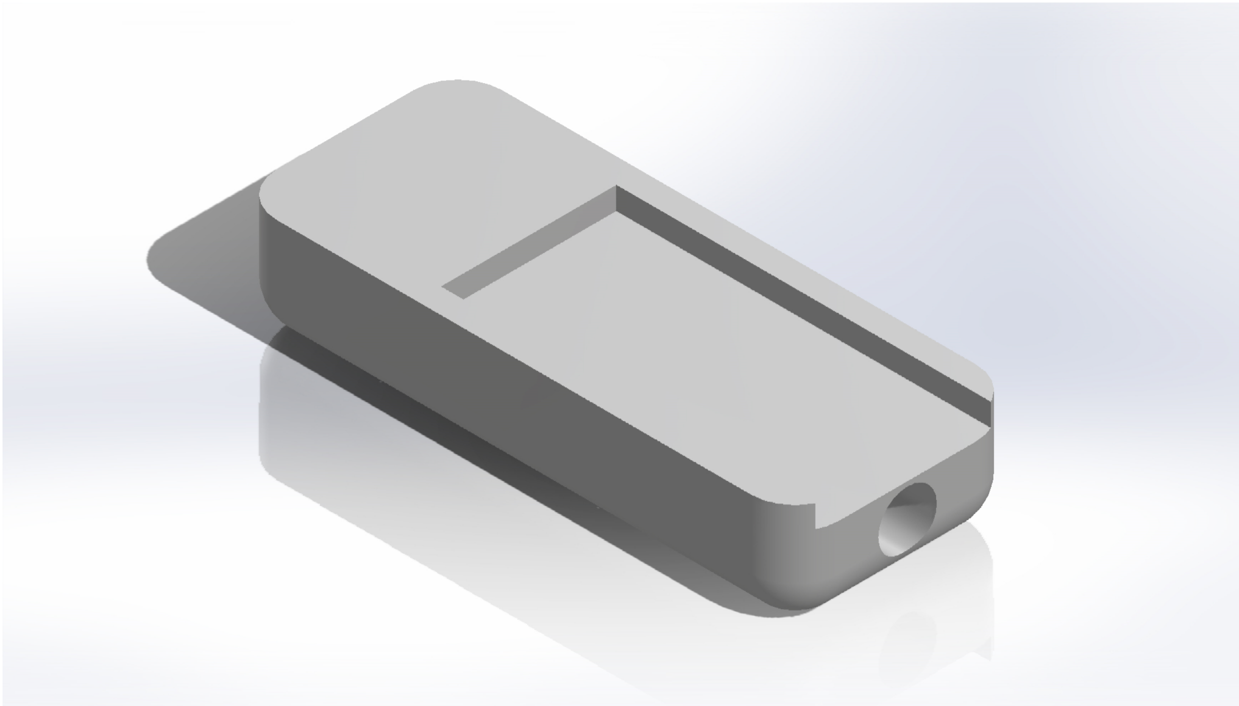


Figure 11: Remote Control Case SolidWorks drawing [by Gianna Inga]

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 [32]. 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 a 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 its superior grip, safety features, ergonomic design, durability, versatility, and ease of maintenance for hygiene. These handles enhance the overall performance by ensuring reliability and user safety as well as comfort.

IV. 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 balance. The 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***

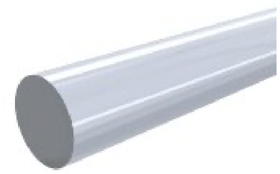
Criteria (Weight)	Aluminum 		Carbon Fiber 		PVC Plastic 	
Weight (30%)	3/5	18%	4/5	24%	5/5	30%
Durability/Tensile Strength (25%)	3/5	15%	5/5	25%	2/5	10%
Sterilizability (20%)	3/5	12%	5/5	20%	3/5	12%
Cost (15%)	4/5	12%	2/5	6%	5/5	15%
Ease of Fabrication (10%)	5/5	10%	2/5	4%	2/5	4%
Total		**67%**		**79%**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

Figure 12: 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 the 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 [17] 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 the 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 [17], 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 [18]. However, in the application of the 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 lower price point than carbon fiber but a slightly higher price point than PVC. The price range of telescoping aluminum rods reasonable for the device range from \$10-\$30 [19], being well within the budget of the device.

Aluminum was ranked highest for *Ease of Fabrication* due to the large availability of telescoping aluminum rods already on the market [19]. 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 [22]. 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 [21], 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 [23]. It is best to avoid using oxidizing agents when cleaning carbon fiber, such as hydrogen peroxide [33], 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 [20]. 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 [25]. 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, the tensile strength rating of PVC plastic is considered to be around 52 megapascals at 20 degrees celsius [26], 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 [27]. Additionally, with frequent scrubbing or wiping down, the outer surface is known to become increasingly matte as the outer finish degrades [27]. 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 [24]. 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*

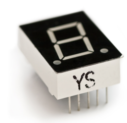
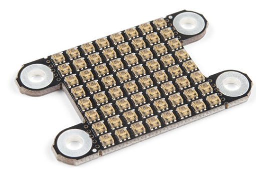
Criteria (Weight)	7-segment display and LED string lights (2 IR remotes)  		LCD touchscreen display (single button) 		8x8 LED matrix (1 IR remote) 	
Therapist Usability (Control Complexity and Weight) (25%)	2/5	10%	5/5	25%	4/5	20%
Patient Visibility (25%)	3/5	15%	5/5	25%	4/5	20%
Ease of Fabrication (Software 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 13: 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 [28] that will be paired with an Infrared (IR) remote. The LED string lights [34] 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 1 in x 0.6in [28]. 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 [35].

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 [36]. 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 the team 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 [36]. 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 [29], 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 [30]. 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 [37] 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 [38]. In addition, there are videos demonstrating how to pair an IR remote to a 8x8 LED matrix with Arduino [39]. 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. 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

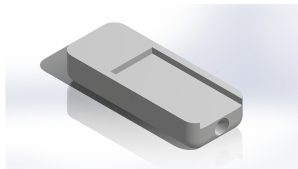
Criteria (Weight)	Remote Control Case 		Moldable Hand Grip 		Ribbed Gym Handle 	
Grip & Control (35%)	2/5	14%	4/5	28%	4/5	28%
Ease of Fabrication (25%)	3/5	15%	3/5	15%	5/5	25%
Modifiable (20%)	5/5	20%	4/5	16%	2/5	8%
Durability (10%)	3/5	6%	3/5	6%	5/5	10%
Cost (10%)	2/5	4%	4/5	8%	4/5	8%
Total		**59%**		**73%**		**79%**

Figure 14: 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 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[32][40].

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[41]. 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 prototypes were printed 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[40]. 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[40], which is well within the budget.

Design 3: Ribbed Gym Handle

The ribbed gym handle design is inspired by the common, daily use of ribbed handles of gym equipment for people to grab and apply force for their physical training. It is an ideal design choice for the handle with a 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 provides 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) [32][41]. 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.

A. 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.

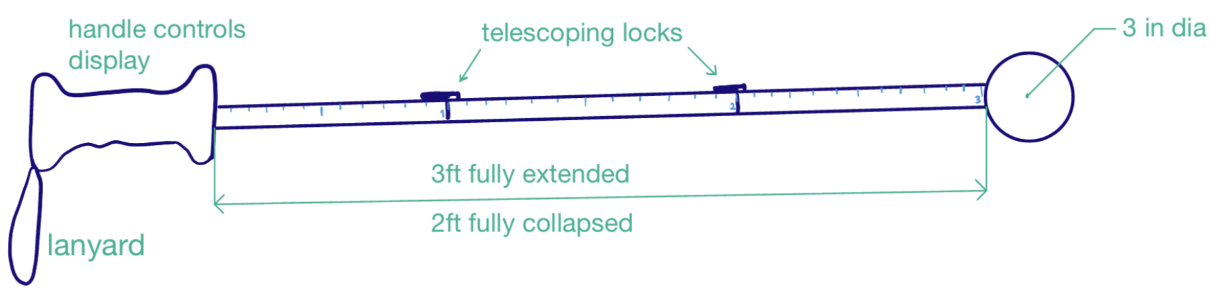


Figure 15: General design of device as per PDS [by Maggie LaRose]

V. Fabrication/Development Process

A. Materials

First, the control rod was decided by purchasing a 36-inch long "Extend-A-Reach" Aluminum Telescoping Rod and then further modified for the prototype design. Due to the time constraints and to satisfy the design criteria of weight, this version of the product was optimal for the device. The rod itself was also engraved with etched measurements of inches using the Universal Laser Cutter and Eastwood Aluma Aerosol Blast Print provided by TEAM Lab.

The circular disk was divided into two parts and was attached to one end of the rod. This disk was 3D printed in PLA using the Ultimaker provided by Makerspace. This material was durable for the protection of electronic equipment and easily printable. PLA is also quite inexpensive, costing \$0.08/gram, and considering the total specifications of the disk, the lid and bottom together costed \$14.80 [42]. For the electronics: an Arduino Uno Microcontroller, Waveshare LCD screen, 10 kΩ resistor, 4 triple A battery pack along with a toggle switch, and multiple wires were incorporated inside the disk component.

On the other side of the rod, the handle was composed of a tactile clicker button, a rubber lanyard at the tip, and was enclosed with foam exercise equipment tubing from a custom order based on the diameter of the rod at the handle part which was 1.18 inches. For the counterweight matter, the fishing spherical steel weights in size of ½ inches and weighing 15g each, were applied but later removed from the final prototype due to their ineffectiveness in reducing the device's weight.

All the materials listed above from online vendors and UW Makerspace which can all be found in *Appendix B: Materials List*.

B. Research Required for Prototype

The team conducted research on each of the different components of the device: the rod design and electronic components. For the rod design, various materials were researched to determine their durability. Ultimately, aluminum was chosen due to its low weight and resistance to chemical cleaners [43]. To reduce the weight and moment of force on the handle of the adjustable rod, team members looked into compatible counterweight options. Although they were not implemented into the final design, it was decided that steel counterweights were the best fit based on their wide availability, durability, and effectiveness in performance. Its density allows for compact designs, saving space while providing the required weight. Steel's durability ensures it can withstand constant use and be shaped and configured to fit specific spaces such as fishing weights. Additionally, to incorporate measurements onto the rod handle, various methods including vinyl cut stickers and laser engraved measurements were considered. It was determined that with water-soluble laser marking spray, engravement was possible. As for the electronic components, research was conducted regarding the coding of an LCD screen and wiring techniques for the LCD screen coupled with an Arduino. From this, an electronic schematic was able to be created and implemented into the prototype.

C. Methods

After ordering the extendable rod, the ends were customized appropriately according to other components that were attached to them. At the end of the rod, the 3D-printed circular disk was attached using a screw and bolt. The circular disk itself as shown in Figure 12 is composed of two parts, the case and the lid, which were initially designed by the team using SolidWorks. The case includes a circular hole at the center that was designed with the right dimensions to fit the Waveshare LCD screen perfectly. The hole incorporated in the case would allow for the Waveshare LCD display to fit perfectly and be displayed to the patient and therapist using the device. The case was also designed with enough space to include all the electronics inside of it. The case and lid have threads that allow them to be tightened like a jar.

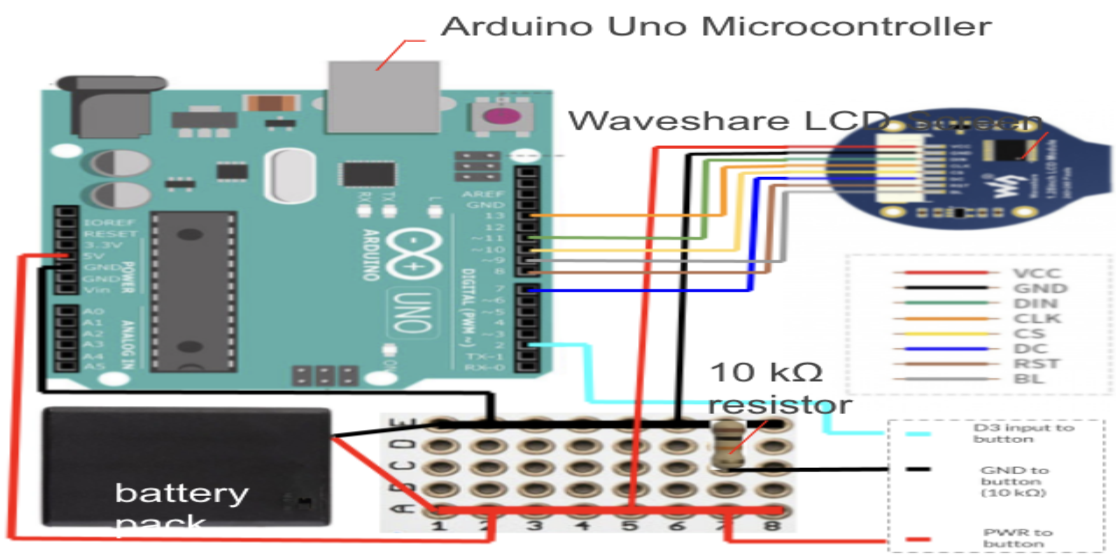


Figure 16: Electronics Schematics

The Arduino Uno microcontroller was programmed with a random dice roller code. When the tactile button on the handle is pressed, a high voltage reading is sensed on a predetermined digital input pin and the code instructs the microcontroller to randomly switch between 6 colors defined in the code. As shown in Figure 11, the LCD screen is connected to various digital input pins of the Arduino in order to display the 6 different colors. The Arduino microcontroller operates on an external supply of 5 volts, so

4 triple A batteries were used to produce a total of 6 volts. An additional perma-breadboard was used to solder connections of the wires from the battery pack, microcontroller, and clicker button. The wires for the clicker button were fed through the length of the hollow extendable rod from the disk to the handle.

After constructing both the rod and electronics, the handle part was modified in which the tactile clicker button the size of a square (0.236 x 0.236 inches) was attached to the carved hole on the other end of the rod. This process was completed using super glue and additional electrical tapings around for the protection of wires and smooth transmission of signals from the clicker. Furthermore, a layer of foam tubing that was originally purchased was cut to an appropriate size based on the rod's diameter to cover up the end of the rod. Lastly, the rubber lanyard was obtained and inserted on the end tip of the rod for wrist and easy hanging purposes for storage after usage.

D. Final Prototype

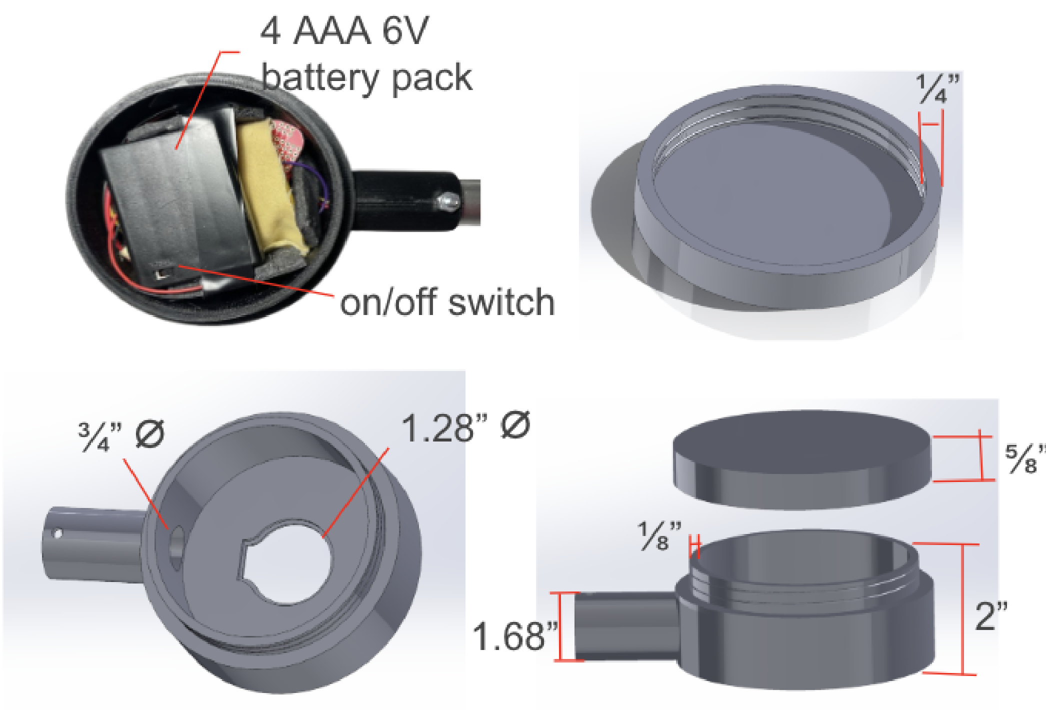


Figure 17: Internal view of the Electronics Case and its Solidworks design schematics

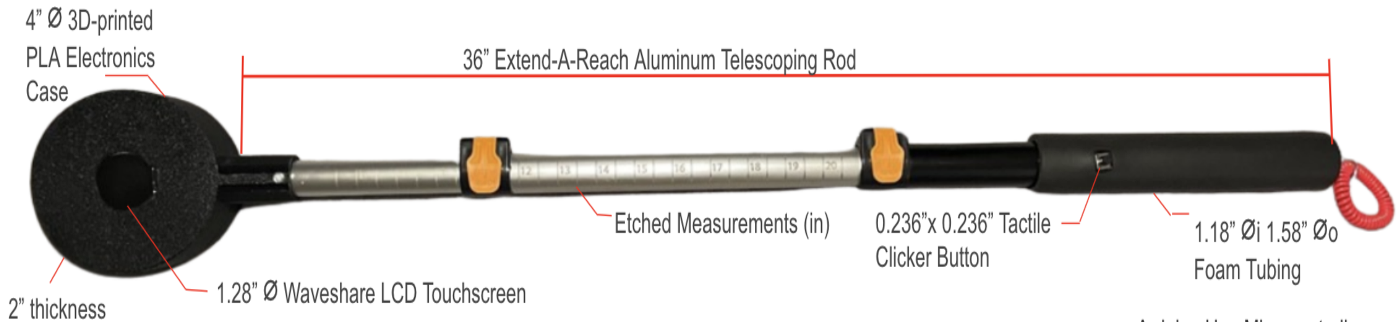


Figure 18: Final prototype with 3D printed disk, LCD screen, handle enclosed by foam tubing with clicker button and elastic lanyard, and a total device weight of 500g.

E. Testing

1. Client Feedback Survey

The device was given to the client, Dan Kutschera, to use for a week in the clinical setting at Encompass Health. A survey was given for physical therapists to complete in order to test the criteria of therapist usability (weight), patient compatibility (fundamental reach test and screen visibility), durability, and intuitiveness. The therapists were given a brief explanation of how to use the device and were asked to use the device with patients working on static and dynamic balance visual scanning exercises. The survey asked physical therapists to rank the weight usability, color identification accuracy, functional reach test compatibility, sanitation, intuitiveness, durability, and on/off switch ergonomics on a scale from 1-5. They were also asked to answer free-response questions such as how frequently the device was used, how long at a time the device was used, and general feedback about device dimensions and screen colors. The full list of questions can be found in *Appendix E: Client Feedback Survey.*

2. Moment and Counterweight Calculations

Based on the low-weight usability score given in the Client Feedback Survey (see *Appendix G*), moment and counterweight calculations were made given four scenarios of device usage. Those scenarios include a fully extended rod with a battery pack in the disk, a fully extended rod with a battery pack on the handle, a half-extended rod with a battery pack in the disk, and a half-extended rod with the battery pack on the handle. The full calculations for all four scenarios can be found in *Appendix F: Moment Calculations.* The free body diagram and sample static equilibrium calculations as seen in figures 14 and 15 reflect the half-extended rod with the battery pack in the disk scenario. The masses of the telescoping rod and the disk were determined using an electronic scale. The masses were then multiplied by the gravitational constant, $g = 9.81\, m/s^2$, to determine the magnitudes of the force vectors. The locations of the disk and rod force vectors were placed on the centroids of the respective parts, assuming the negligible mass of the foam handle and tactile press button on the telescoping rod.

Point A represents the location of the user's hand when operating the device. As pictured in figure 19, point A was placed immediately to the right of the tactile push button. In order to simplify moment calculations, the interaction between the user's hand and the device was allocated to a concentrated point. The reaction moment at point A, Ma, represents the effort the user must exert to resist the dipping moment of the rod due to the combined force vectors from the disk and the rod. The counterweight, Cw, is a solution to the large moment problem and seeks to counteract the force vectors by creating an Ma of zero. The theoretically ideal counterweight Cw was determined by setting Ma in the equilibrium equation equal to zero and solving for Cw. The functions between Ma and Cw were represented graphically for the four scenarios in *Section VI. Results: Moment and Counterweight Calculations.*

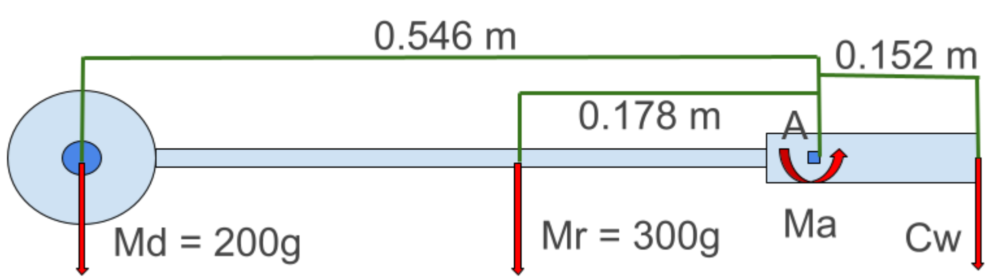


Figure 19: Free body diagram for half-extended rod with battery pack in the disk. The reaction moment represents contact between the user's hand and the handle. The applied counterweight on the end of the handle intends to minimize the reaction moment at point A due to the large weight concentration in the disk.

$$F = mg \qquad mass\ rod = 300g \qquad mass\ disk = 200g \qquad g = 9.81\, m/s^2$$

$$F_{rod} = (0.300\, kg)(9.81\, m/s^2) \qquad F_{disk} = (0.200\, kg)(9.81\, m/s^2)$$

$$\Sigma Ma = 0 = F_{rod}(0.178\, m) + F_{disk}(0.546\, m) - Cw(9.81\, m/s^2)(0.152\, m) - Ma$$

$$Ma = 1.595 - 1.49Cw$$

Figure 20: Static equilibrium calculations for the scenario of half extended rod with the battery pack in the disk reveal the function of reaction moment at point A versus counterweight

3. Usability Weight Testing

Usability weight testing was performed in order to determine the realistically ideal applied counterweight against user comfort. A focus was placed on the half-extended rod with the battery pack in the disk scenario because the therapists reported a preference for using the device at half-extension, and the battery pack was fabricated to be encased in the cylindrical electronics case. The test was conducted with 6 healthy, ~20-year-old college students. As for the testing itself, the protocol consisted of the team members of the group all using a pain scale to rate the discomfort and pain they felt while holding the device with various different amounts of counterweights applied to the device. Each team member held the device with a 0 kg counterweight applied and rated their pain to serve as a control measurement. Four different counterweights were chosen for the test, including 1.07 kg (the x-intercept on the half-extended disk battery curve, where Ma = 0), 0.535 kg, 0.267 kg, and 0 kg. The counterweights were created by filling a plastic bottle with the correlated mass of water and then placing it inside a plastic bag which was hung from the end of the foam handle. The subjects were asked to hold the device at half extension at an angle of 180° in relation to the forearm (pictured in figure 16) and rank the level of pain experienced according to the Pain Assessment Scale as pictured in figure 17. The data was graphically interpreted as a function of applied counterweight versus pain, which can be found in *Section VI. Results: Usability Weight Testing.*

Figure 21: Usability weight tests were conducted at half rod extension with counterweights attached to the end of the foam handle. Test subjects held the device at 180° and ranked user comfort via the Pain Assessment Tool.

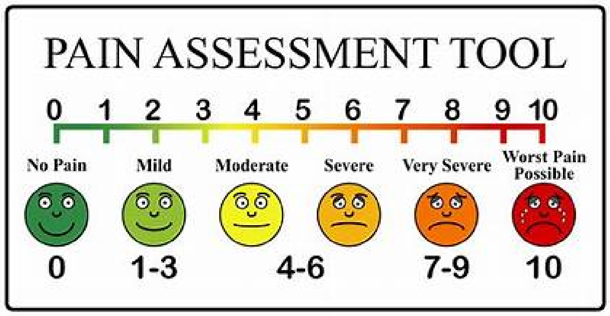


Figure 22: The Pain Assessment Tool was used during usability weight testing to quantify the user comfort versus the various counterweights applied to the end of the rod handle [44].

4. LCD Screen Visibility Testing

LCD screen visibility testing was conducted in order to evaluate the patient usability design criteria. The test design specifically aimed to evaluate how certain colors affect the ease of identification and length of reaction time. Test subjects were asked to stand 5 feet away from the device with the screen held at eye level. Then, 10 colors were randomly displayed on the screen that the subjects were asked to identify. Test subjects were asked to close their eyes or place a visual barrier between them and the screen in between colors. The accuracy of the identification of each color was recorded for each of the 10 trials. Subjects were then asked to repeat the process but at distances of 10, 15, and 20 feet. At a distance of 20 feet, the reaction time for color identification was recorded in addition to identification accuracy. For continuity purposes, subjects were given a sheet of cardboard to cover their eyes in between colors. This aided in decreased experimental error for timing in that the stopwatch was started immediately when the cardboard was lowered and then stopped immediately when a color was spoken.

Color accuracy data was aggregated by color and graphically represented as an average in percentage. Reaction time was also aggregated by color and represented as an average. This data can be found in *Section VI. Results: LCD Screen Visibility Testing.*

Figure 23: LCD screen visibility testing was conducted on 6 healthy ~20-year-old subjects at distances of 5', 10', 15', and 20' for 10 trials each. Subjects were asked to identify the color displayed at eye level. Accuracy by color and reaction time by color (only at 20 feet) were recorded for each trial.

VI. Results

1. Client Feedback Survey

The team completed the first version of the prototype and delivered it to the client, Mr. Kutschera, to perform testing with his patients at the Encompass Health clinic. The team asked the client to fill out an associated survey to gather feedback about the use of the device. The survey consisted of twenty questions, that were multiple choice and short answers, to gauge how the client rated the device. The main design criteria that the team was focused on evaluating were Therapist Usability (Weight of the device), Patient Usability (Screen Visibility), Patient Usability (Functional Reach Test), Durability, Intuitiveness, and Ease of Sanitization.

As for the Therapist Usability (Weight) category, the device scored 43%, which was quite low. The reason for a low score in this category was that many questions that were centered around the weight of the device and the difficulty of carrying the device scored poorly. Therefore, when averaging the scores of these questions, the device received 43%. It was concluded that the device was too heavy for the therapist to hold during his intervals of holding the device with each patient. He remarked that the device was quite difficult to hold and affected his usability. Survey results also showed that he could not stand to hold the device for very long at all, due to the weight that was concentrated at the top of the device. The weight concentrated on one end of the device was due to the battery, Arduino, other electronics, and

3D-printed casing, all being in one compact spot. The end of the device is heavy and causes a large moment where the user holds it.

For the Patient Usability (Screen Visibility) category, the device was rated 60%. When asked if patients were able to identify colors on the display accurately, the therapist responded with ⅗, which equals 60%. Not all patients had difficulty in identifying the colors, but some did, and that was the importance of noting. In order for this device to be compatible with all stroke neglect syndrome patients, the device must be compatible with all types of patients, especially those who may have vision impairments or other conditions that may cause this exercise to be more difficult for them than others. In addition, the therapist noted that the colors were too small and off shades than what he was expecting. The color that was the most difficult to identify was green, as it was easily mixed up with yellow. This aspect is important in noting, because it brings awareness to the fact that the colors need to be more primary colors with clear shades that all patients will recognize. It may not be necessary to have a plethora of colors, but rather a few colors that are exactly primary and may not cause any confusion. When displayed, the colors would take up the entire diameter of the screen display, so there is no way to change the code to make the colors bigger. However, the team could try to change the display entirely and enlarge the display so the diameter is bigger, to around 3” instead of 1.28”.

For the Patient Usability (Functional Reach Test) category, the device was rated at 40%. This was mainly rated based on two questions from the survey. One question being centered on the effectiveness of the extending and collapsing mechanism of the rod, and the other question being how compatible was the device for the functional reach test. The device scored a 40% for the effectiveness of the collapsing and extending mechanism. The device incorporates a 2-3 foot extendable rod that was purchased on Amazon (Extend-A-Reach). The rod can have different lengths and can adjust accordingly to any length between 2-3 feet, which was the exact client specifications. However, the score for this question was low, as there was some resistance when trying to expand or collapse part of the rod. This was due to the internal wiring that stretched from one end of the rod to the other end. The wiring was connecting the clicker on the handle end of the rod, to the battery and electronics on the head of the rod. When trying to open and close the extension of the rod, the wiring sometimes got caught and caused extra resistance on the mechanism. The team strongly recommended that the client did not try expanding or collapsing past a certain point less than 2 feet, because the wiring would get caught and could ultimately destroy the electronics component. Therefore, this aspect of the device needed to be operated with extra caution. After receiving the rod back from the client, he changed his specifications and said he no longer wanted the extra foot of extension, and that the rod only needed to be extended at ½ length, just under 2 feet. In the future, he said he wanted to reduce the length of the rod. The team concluded that these reasons were why the compatibility of the functional reach test scored low at 40% as well. Before handing the prototype to the client initially, the team had laser engraved measurements onto the rod to act as a measuring tape or ruler when performing the functional reach test. However, the client returned with feedback saying that the measurements were etched the wrong way, which would require him to compute mental math while working with the client, which increased the difficulty in easily being able to acquire the distance that his client was able to reach. This was another main reason for the low score in this category. After receiving that feedback, the team fixed the mistake and re-engraved the measurements in the correct direction that the client specified. This adjustment would help increase the scoring of this category if the client were to give us feedback again.

For the Durability category, the device scored a high score of 100%. The survey mainly asked about how the client felt about the durability of the device, and if he felt that the device was going to break at any point during his usage. The client reported that the device was very durable and could withstand usage up to 40 hours a week. This was a positive rating from the client, as he felt that this device could be used for long periods of time. This is also important for the client as he would not want to be using the device if it required extreme maintenance often.

For the Intuitiveness category, there were a couple of questions that were used to rate this category. One question was simply asking how intuitive the device was to use for the first time. The other questions were about how easy it was to unscrew the cap of the 3D printed casing for the battery, and how convenient it was to turn on and off the battery in between uses. The intuitiveness question got 80% as the client felt it was very intuitive once he turned on the device and played around with the clicker. Once he was comfortable with the device and how it works, he felt that anyone could use the device as it was easy to operate. However, he felt that there were some cosmetic issues that could be fixed in the future. He felt that the screw cap was slightly difficult to unscrew, and the team agreed with this issue as well. The way that the casing was printed on the 3D printer, the cap took extensive screwing to get the cap on to encase the electronics. The casing cap was never fully tight when fully screwed, which posed a constant worry of the casing falling off while the device was in use. In addition to the question about the screwing of the cap, the team also asked about the convenience of the turning on and off of the battery within the casing. That received a score of 3 out of 5, which was 60%. The client reported that the switch to turn the battery on and off functioned properly, but it could be implemented in a more convenient way. In order to fix this issue, the team assessed the feedback and decided that the next step would be to implement an external, easy-accessible on/off switch on the device. This way, the user does not have to unscrew the cap to the casing holding the battery and electronics, and would overall be seen as more convenient.

The final criterion that was scored was the ease of sanitization, which received a high score of 100%. The client specified that cleanliness is very important in a clinic when working with various patients. Sanitation and cleanliness needed to be valued highly when creating the device, therefore the team chose an aluminum rod for the rod component of the device. Aluminum has little to no degradation of the material or finish after being sanitized with an all-purpose cleaner. The client felt that he could easily clean the device with a cleaner in between uses for patients that he sees, thus leading to a high score of 100%.

Design Criteria	**Rating (%)**
Therapist Usability (Weight)	43%
Patient Usability - Screen Visibility	60%
Patient Usability - Functional Reach Test Compatibility	40%
Durability	100%
Intuitiveness	64%
Ease of Sanitization	100%

Figure 24: Ratings of design criteria from Client Feedback Survey. Ratings were made on a scale from 0-100%

2. Moment and Counterweight Calculations

The functions of applied counterweight Cw and reaction moment at point A are graphically represented as seen in figures 20 and 21. The applied counterweights where reaction moment Ma equals zero are represented by the x-intercepts for each curve. For the half-extended rod moment, the theoretical counterweights were 0.65 kg and 1.07 kg for the battery in the handle versus the battery in the disk, respectively. The x-intercepts for the full extended rod were 1.11 kg for the battery on the handle and 1.70 kg for the battery in the disk. Given that these calibration curves resulted from calculations and not raw testing data, the R^2 values were the primary error statistic and came out to be equal to 1 for all four scenarios. Any other statistic such as standard deviation or standard error was considered redundant and was excluded from the data analysis.

The value for the half-extended rod moment with the battery in the disk, 1.07 kg, was used as a baseline for usability and counterweight testing protocol. Going above the zero moment counterweight value would serve as a detriment to the usability of the device, causing a moment in the opposite direction to occur and adding unnecessary weight. Therefore, counterweight testing was designed to begin at a counterweight of 0 kg and end at the maximum of 1.07 kg.

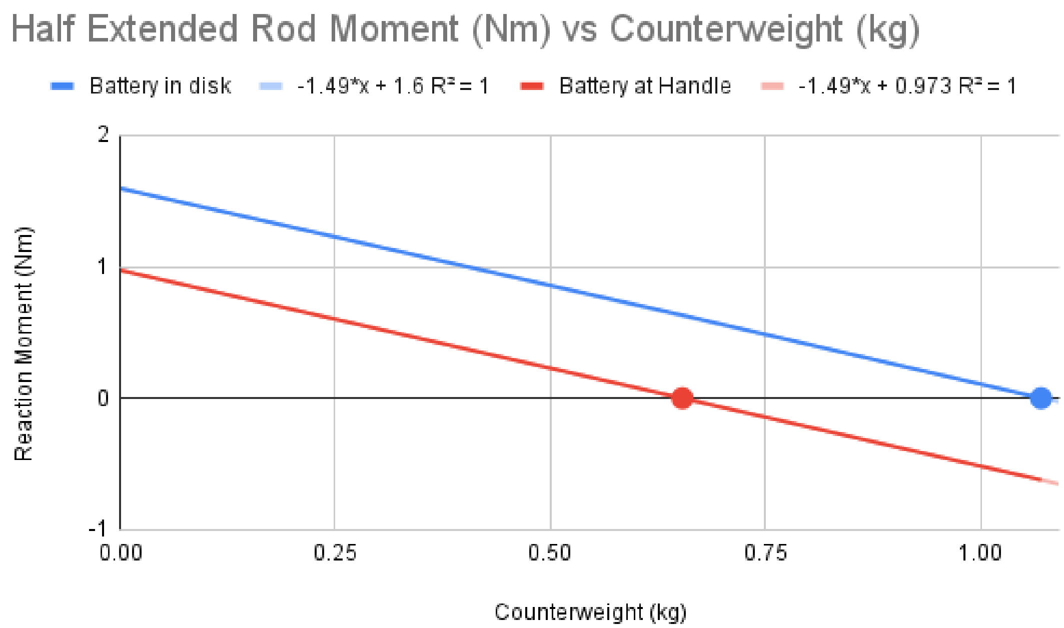


Figure 25: The function of applied counterweight versus reaction moment of the half-extended rod. The blue line represents the battery in the electronics disk scenario and the red line represents the battery pack on the handle scenario. The labeled data points represent the applied counterweight where the reaction moment equals zero. (0.65kg and 1.07 kg)

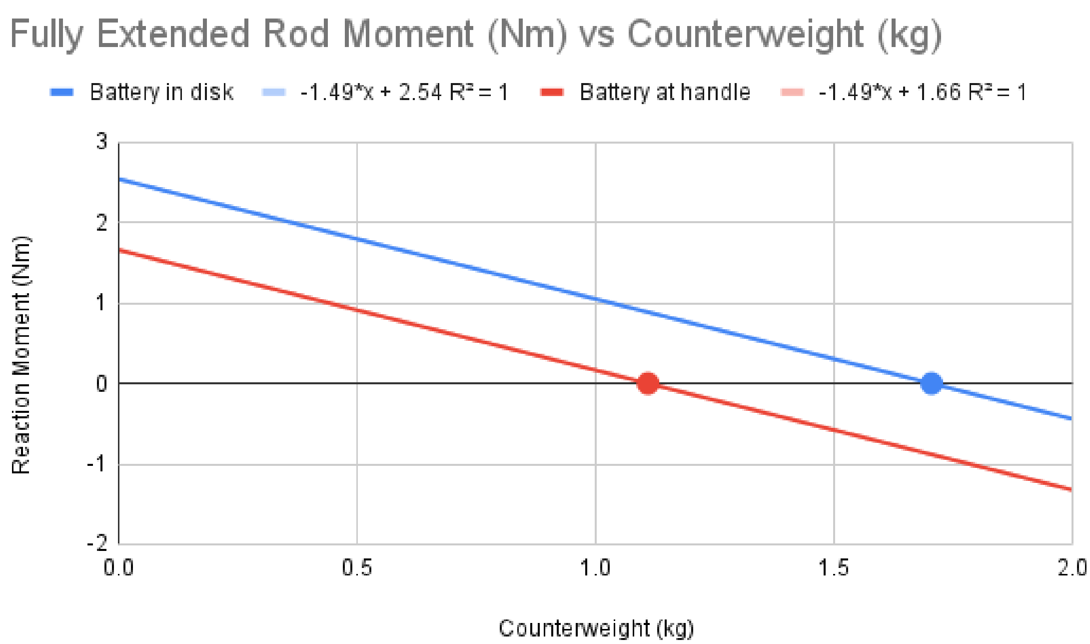


Figure 26: The function of applied counterweight versus reaction moment of the fully extended rod. The blue line represents the battery in the electronics disk scenario and the red line represents the battery pack on the handle scenario. The labeled data points represent the applied counterweight where the reaction moment equals zero. (1.11 kg and 1.70 kg)

3. Usability Weight Testing

The data collected from usability testing was plotted with a quadratic type fit curve with an R^2 value of 0.961. In general, it was discovered that the maximum applied counterweight of 1.07 kg caused a larger pain scale rating than expected, as the added weight began to outweigh the benefits of canceling out the reaction moment. Therefore, the minimum value from the curve fit equation, where the user pain value was the lowest, was deemed to be the ideal applied counterweight and should be aimed for in the design. The realistically ideal counterweight value was 0.69 kg at a pain scale rating of 2.26/10. The standard error for the usability weight experiment was 0.478. Additional trials at incrementally smaller counterweights should be performed in order to decrease this value. As discussed in Section *VII, Discussion,* future work for the Dynamic Balance Device involves moving the battery pack to the handle, which in turn would decrease the reaction moment at A and might eliminate the need for an applied counterweight. Additional testing for the battery in the handle scenario would need to be conducted in order to evaluate the correlated pain scale rating.

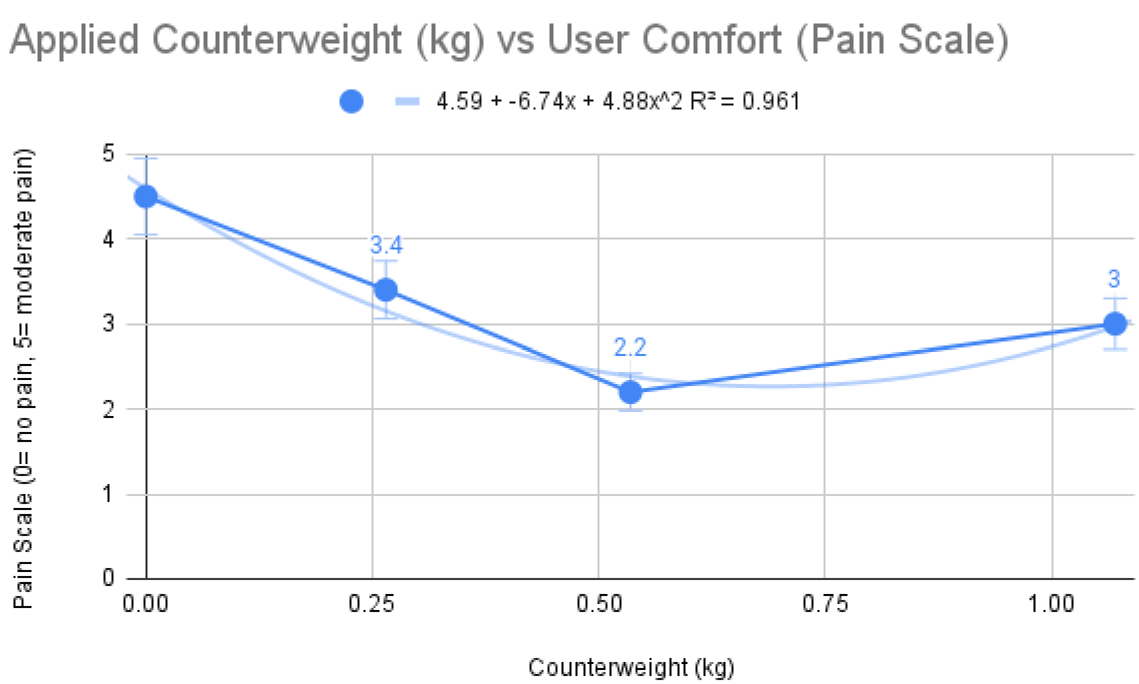


Figure 27: The function of applied counterweight on the end of the foam handle versus reported user comfort via the Pain Assessment Tool. The test was conducted on 6 healthy ~20-year-old subjects at four different counterweights (standard deviation = 0.957 & standard error = 0.478).

4. LCD Screen Visibility Testing

The data collected from the Screen Visibility Testing protocol is displayed in figure 23 below, which consists of a bar chart demonstrating the average reaction times to identify each color displayed on the screen. There are 6 possible colors to be displayed: Red, Yellow, Green, Light Blue, Dark Blue, and Purple. The reaction times for red had the lowest reaction time of 1.034 seconds, which showed that red seemed to be the easiest color to identify. However, green had the highest reaction time with an average of 1.422 seconds. This helped the team conclude that green was the most difficult color to identify, as it took the longest for the subjects to identify the color. All other colors had pretty similar reaction times of between 1.1 to 1.25 seconds. In addition to tracking reaction times for each color, the accuracy of the trials was also recorded. The team monitored which color was randomly selected and whether or not the subject accurately identified the color from the 20-foot distance. This data is summarized and can be found in figure 24, which shows the identification accuracy of each of the 6 colors on the display. Green was the color that received the lowest accuracy of 89.1%, meaning green was the color that was incorrectly identified the most. All other colors received identification accuracy results of 100%, meaning none of the subjects had difficulty in identifying red, yellow, light blue, dark blue, or purple. These results are important to take into consideration in terms of the overall effectiveness of the device, because this device aims to help stroke neglect patients, who may or may not have other conditions hindering them from identifying colors accurately. The subjects in the LCD visibility testing were 6 healthy ~20-year-olds. However, the patients who will need this device are much older and may have some pre-existing health conditions, such as vision impairment or aphasia, that can hinder their judgment or ability to guess the color accurately. It is important to note that the team must make an adjustment to the color green, as that was highly guessed incorrectly by 20-year-olds, therefore 65+ year-olds may have a harder experience in guessing correctly. In order to make this device as useful for the therapist and as effective for the patient as possible, these adjustments must be made. Furthermore, all the colors must be reviewed and ensured that they are primary colors that can be easily identifiable by individuals of most ages, and even those that can be visually impaired.

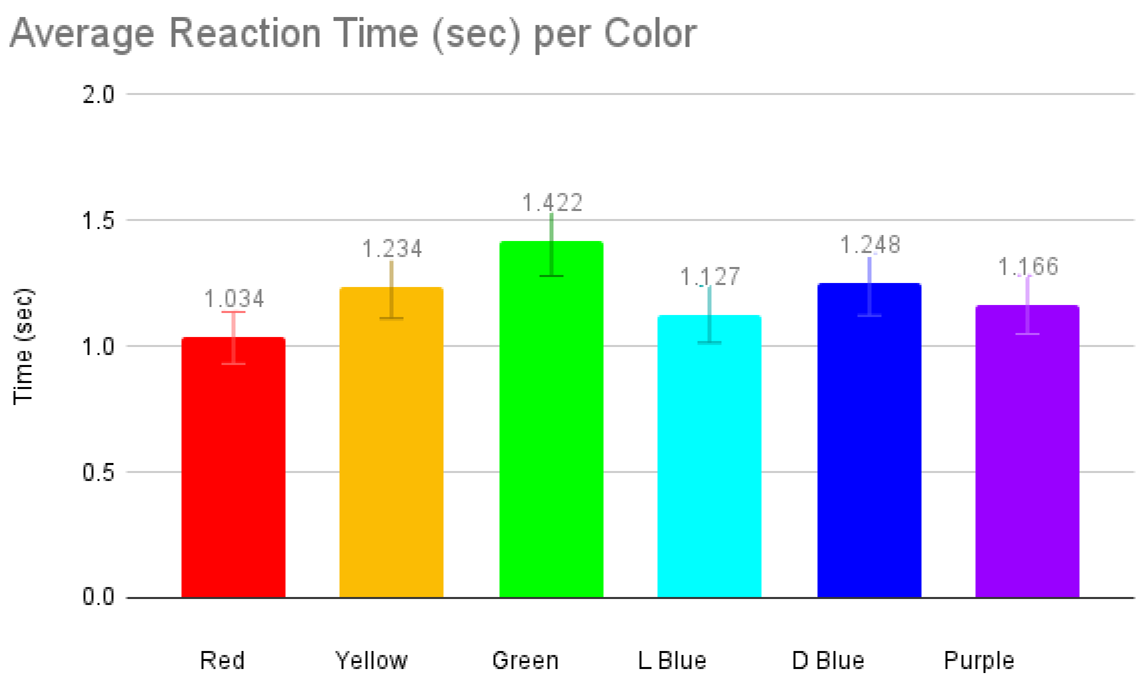


Figure 28: The average reaction time to identify the color displayed on the LCD screen from a distance of 20’ with 6 healthy ~20-year-old subjects for 10 trials each (standard deviation = 0.132 & standard error = 0.0537).

LCD Screen Color	Identification Accuracy (%)
Red	100%
Yellow	100%
Green	89.1%
Light Blue	100%
Dark Blue	100%
Purple	100%

Figure 29: Color Identification Accuracy Table

VII. Discussion

The implications of the design can be seen after the completion of testing and research. There are no current existing competing designs that fit all the client's specifications. The Bioness Integrated Therapy System, a competing design that allows for cognitive post-stroke therapy, can only be used while standing still and doesn't allow for dynamic exercises [3]. The lack of devices that allow for cognitive therapy to occur during dynamic balance exercises is the driving force for the creation of the dynamic balance device. Physical therapists were given the prototype to test with patients and feedback was positive, they had many ideas on how to improve and advance the device and were wondering when they could get the device back in the office. Such reactions show the want and actual application of the device in post-stroke physical therapy. The weight was the biggest complaint from the physical therapists and they scored therapist usability at 43% in the feedback survey because of such. Moving forward, reducing the device's weight, especially at the end of the rod, will be the main priority to increase client comfort and usability. The feedback also showed that the device was intuitive to use as ease of use scored 64% which is important as the client informed us that he and his coworkers would all use the device and should be easily understandable.

In the conduct of research, there were no ethical issues or considerations that arose. However, the issue of making a profit in the industry and creating an affordable, easily accessible product that aids in physical therapy does exist. As no device allows for dynamic balance exercises with cognitive therapy, the market would be unmatched and a difficult decision would need to be made about setting a price.

After evaluating the device, the weight needs to be reduced because right now, it hinders the usability of the device. The weight could be reduced by redesigning the 3D print to have thinner walls or using a smaller battery pack. Balancing the weight to increase user comfort would be achieved by locating the battery pack closer to the handle or adding a counterweight below the handle. From LCD screen visibility testing, it was clear that green was the most difficult color to identify, and thus if healthy ~20-year-olds have trouble identifying a color, then elderly post-stroke patients will too. The color green should be either changed to a darker green or not included in the possible colors.

Possible sources of error could be from not doing enough trials as well as biased subjects. In the usability weight test, all subjects only held the device with each counterweight once and rated their comfort level. Doing multiple trials may have yielded a more accurate response and thus a lower standard error. In the LCD visibility test, the team served as the subjects and thus they had previous knowledge of what colors would be presented and what they look like. In the test, it may have been easier for the subjects to identify slight differences in the colors because of continued work and fabrication with the LCD screen. There also may be underlying visual impairments the subjects are unaware of that may have caused an error in the LCD visibility test.

VIII. Conclusions

The client requested a device to be a cognitive challenge used during dynamic balance exercises for post-stroke rehabilitation physical therapy as no device on the market currently fulfills such requests. To satisfy these requirements, the team created a design that incorporated an LCD touchscreen positioned in a PLA 3D printed case with an Arduino microcontroller and battery pack. The 3D-printed case resides on the end of an extendable aluminum rod and the LCD screen is controlled by a button embedded in the handle of the rod.

The team successfully programmed the LCD touchscreen to display one of the six chosen colors at random with the click of a button. The team decided the device would randomly generate colors as opposed to a set cycle to ensure the patients wouldn’t know the next color and hinder the cognitive therapy exercise. The team also successfully soldered the Arduino controller, button, LCD screen, and battery pack together by wiring strung through the hollow part of the aluminum rod. The button was secured flush with the handle grip and the Arduino microcontroller, LCD screen, and battery pack reside in the 3D-printed case. The wiring was taped down securely in the 3D-printed case to not dislodge the soldering of the Arduino and slack was left in the rod to allow for the extension and shortening of the device. Another successful aspect of the device was the creation of the 3D printed case with minimal dimensions, an exact hole and ledge for the LCD screen, connection to the rod, and screw backing. The team decided to create a ledge for the LCD screen to be more flush with the outer edge of the case and not hinder the patient's view of the screen. The inclusion of a custom-made carbon fiber rod in the current prototype was unsuccessful although it was the chosen material for the rod, because of the lengthy processing and shipping time that wouldn't be feasible in the short timeline of the semester.

In terms of future work, the prototype will need to be lighter for optimal client comfort, especially reducing the weight at the end of the rod. This weight reduction can be achieved by redesigning the 3D case print to have thinner walls and using a smaller battery pack. To reduce the moment on the handle, a significant cause of user discomfort, a counterweight can also be added below the handle or the location of the battery pack closer to the handle. Implementation of a carbon fiber rod is another future work as it is a stronger, lighter material that would increase the longevity of the device as well as reduce its weight. The client would also like the rod to be shorter, as after the physical therapist testing, he reported that all the physical therapists used the device at half the potential length and there was no need for any additional length. The next steps would also include redesigning the 3D-printed case backing for increased durability and a more permanent closure if the battery pack is moved out of the case. An accessible on/off battery switch would also aid in user ease instead of having to open the 3D-printed case before and after every usage. Other changes the client requested that were not possible during the semester were a larger LCD screen (3" diameter), adding a feature that displayed shapes and symbols, and an audible response to touchscreen contact.

Mr. Kutchera was very impressed and happy with the team's work and progress throughout the semester. He and his coworkers were excited to get the prototype back into the office for their physical therapy sessions again. Mr. Kutchera is very passionate about the project and is looking forward to the improvements that are possible for the device. The current prototype achieves many of the requirements set forth by Mr. Kutchera and is a working prototype to assist in dynamic balance exercises for post-stroke patients.

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Appendix

Appendix A: Product Design Specifications

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. The 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 yardstick 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 the 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; the device must weigh 5 lbs or less
- Device must be easily storable, professionally built, and easily sanitized as it will be used every day 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 yardstick 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 a one-year shelf life and should be reliable

structurally and electronically, for the therapists to use every day. 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 the storage hook between 20-50 times a day based on the 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 onto the device. Therefore, the weight of the device should be kept to an absolute minimum, with a maximum of 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 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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Appendix B: Materials List

Item	Description	Manufacturer	Mft Pt# (ASIN #)	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total	Link
List of Device Components										
1.28inch Round LCD Display	240×240 Resolution, IPS, SPI and I2C CommunicationWaveshare 1.28inch Round LCD Display Module with Touch Panel	Waveshare	B095X1JDCM	Amazon	114-8939615-5591458	10/18/23	1	$20.64	$20.64	LCD Display
1.5-3 ft Long Paint Roller Extension Pole	Multi-Purpose Telescopic Extension Pole with Universal Twist-on Metal Tip // Lightweight & Sturdy Extendable Pole for Painting Dusting and Window Cleaning	EXTEND-A-REACH Store	B08LL28XZW	Amazon	114-0976274-3115435	10/18/23	1	$16.85	$16.85	Paint Roller
Arduino Uno REV3	14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button	ARDUINO	B008GRTSV6	Amazon	114-8431890-5795403	10/25/23	1	$29.42	$29.42	Arduino
Coin Cell Battery Holder	QTEATAK 6 Pcs 2 x 3V CR2032 Button Coin Cell Battery Holder with Leads On Off Switch	Jianfeng Store	B08113GW84	Amazon	114-0654328-5760241	10/25/23	1	$7.37	$7.37	Coin Cell Battery
Battery Holders	Battery Holder that is included with the switch (On/Off) for placing 4 triple A battery	N/A	N/A	UW Makerspace	2335	10/25/23	1	$2.02	$2.02	N/A
Batteries	triple A alkaline battery & Coin Battery	N/A	N/A	UW Makerspace	2338	10/25/23	1	$3.15	$3.15	N/A
Coin battery	Coin battery	N/A	N/A	UW Makers	2463	11/3/2023	1	$1.21	$1.21	N/A

				pace						
3D printing Circular Disk	Using PLA material to print out pre designed structure component of a circular disk with hollow circle at the center	UW Makerspace	5437599321	UW Makerspace	2472	11/3/23	1	$3.44	$3.44	N/A
Foam Tubing	Tubing for Handle Grip Support, Pipe Insulation, 30mm ID 40mm OD 1m Length Black	uxcell	B0951ZB92R	Amazon	114-2878938-7061036	11/9/23	1	$12.65	$12.65	Foam Tubing
Wires	4ft long wires (one double & one single)	N/A	N/A	UW Makerspace	2665	11/10/23	2	$0.42	$0.84	N/A
Soldering Iron Kit	Soldering Iron 60W Adjustable Temperature, Solder Wire, Soldering Stand, Wire Cutter, Solder Tips, Desoldering Pump, Tweezers, Solder Paste, Heatshrink Tubes	Plusivo	B07S61WT16	Amazon	112-1403659-3901065	11/10/23	1	$18.98	$18.98	Soldering
3D printing Circular Disk #2	Using PLA material to print out pre designed structure of a circular disk with hollow circle at the center, updated version from the previous one	UW Makerspace	5527853695	UW Makerspace	76	11/16/23	1	$7.84	$7.84	N/A
								TOTAL:	**$124.41**	

Appendix C: Fabrication Plans

SolidWorks 3D Printed Casing

1. Measure Arduino microcontroller, battery pack, LCD touchscreen
2. Create SolidWorks part: Disk
3. Create a sketch with
    a. 3 circles centered on the origin with radii: 2.25”, 1.85”, .7005”
    b. A .5725” vertical line .8155” from the right plane
    c. Tangent Arc connecting the edges of the line to the smallest circle

4. Boss Extrude the base excluding the smallest circle and the area created by the tangent arc and line 1.8”
5. Cut extrude the middle circle 1.65”
6. Create a sketch on the bottom of the inside of the cylinder and outline the smallest circle, tangent arcs, and line segment by .05”
7. Cut extrude the sketch .085”
8. Create a sketch on the top edge of the cylinder and create a circle centered on the origin with a 2” radius
9. Cut extrude the area between the 2” circle and the outer edge of the cylinder .5”
10. Add right-handed threads to the cut extruded edge of the cylinder with the following details:
    a. Cut thread
    b. Type: Inch Die
    c. Size: #10-24
11. Create a hole with hole wizard on the side of the cylinder
    a. Position the center of the hole 1.2” from the front plane
    b. Size: 1/16
    c. Diameter: .75 in
12. Create a plane 4” from the right plane
13. Create two circles centered on the side cylinder hole on the new plane with radii: .47”, .6”
14. Boss Extrude the area between the circles up to the surface of the cylinder
15. Create a vertical hole with hole wizard on the new extruded part
    a. Positioned .25” from the created plane
    b. Size: #97
    c. Diameter: .1875”
    d. Extrude through both sides
16. Create a new SolidWorks part: Lid
17. Create a sketch with a circle centered at the origin with a 2.25” radius
18. Boss Extrude the circle .65”
19. Create a sketch on the circle flat edge with a circle centered on the origin with a 2.025” radius
20. Cut Extrude the circle .5”
21. Add right-handed threads to the inner edge of the lid with the following details:
    a. Extrude Thread
    b. Type: Inch Die
    c. Size: #10-24

<u>Laser Engraving of the Rod</u>

1. Create a vector engraving file using Adobe Illustrator
2. Prepare the rod by taping off sections of the rod with painter's tape to avoid spray paint contact
3. Spray section for the intended engraving with CerMark: Black Laser Marking Spray
4. Upload the vector file onto the computer connected to the laser cutter
5. Align the rod and laser cutter
6. Set the settings to metal engraving, CerMark, 0.1 mm depth
7. Start the laser cutter
8. Take off the painter's tape

9. Wash off excess paint from the rod using a wet washcloth

Gym Handle

1. Order Foam tubing from Amazon
2. Measure the length needed from one end of the rod to the clicker button on handle
3. Cut foam tubing and fit the tubing over the rod to create the final handle

Electronics

1. Order an Arduino microcontroller set, battery pack, wires, waveshare LCD screen, and soldering kit from Amazon.
2. Prepare the codes for Arduino to run sequences of commands that display 6 different colors at random order.

Arduino code for Waveshare LCD Screen, random dice roller

```
#include <SPI.h>
#include "LCD_Driver.h"
#include "GUI_Paint.h"
#include "image.h"

void setup(){

  Config_Init();
  LCD_Init();
  LCD_SetBacklight(1000);
  Paint_NewImage(LCD_WIDTH, LCD_HEIGHT, 0, BLACK);
  Paint_Clear(BLACK);
  Paint_DrawString_EN(50, 120, "Click to Begin", &Font16, WHITE, WHITE);
  delay(3000);
  Paint_Clear(BLACK);

  const int button = 2;
  pinMode(button, INPUT);

  randomSeed(analogRead(0));

}
```

```
void loop(){

  if (digitalRead(2) == HIGH){
    int result = rollDice();
    if(result == 1){
      Paint_Clear(BLUE);
    }
    if(result == 2){
      Paint_Clear(YELLOW);
    }
    if(result == 3){
      Paint_Clear(GREEN);
    }
    if(result == 4){
      Paint_Clear(RED);
    }
    if(result == 5){
      Paint_Clear(MAGENTA);
    }
    if(result == 6){
      Paint_Clear(GBLUE);
    }
    delay(2000);
  }
}

int rollDice(){
  return random(1, 7);
}
```

3. Reference the Arduino microcontroller electronics schematic from the Waveshare website [36]
4. Plan out the general outline of which wires are connected to which inputs of the electronics (for Arduino, LCD screen, clicker button)
5. Begin soldering on wires onto the assigned positions
6. Manually place all the electronics including soldered wires and sets into the circular disk.

Appendix D: Testing Protocols

Holding Testing:

1. Hold the device with the dominant arm fully extended outwards 180 degrees.

2. Record the total time it takes to feel: 1. Uncomfortable (pain scale of 5) and 2. unable to hold up anymore (pain scale of 8).

3. Repeat the process with the non-dominant arm.

Holding testing was performed with the fully extended rod held 180 degrees in relation to the forearm and subjects were timed for beginnings of discomfort and maximum effort

Usability Weight Testing:

1. Ask the subject to hold the half-extended rod with no counterweight attached and rate pain on a scale from 1-5.

2. Attach 1.07 kg counterweight to the end of the handle

3. Have each team member hold the rod and rate pain on a scale from 1-5.

4. Repeat the process for counterweights of 0.535 kg, 0.268 kg, and 0.134 kg.

LCD Screen Visibility Testing:

1. Begin with the screen displaying the red color and set the screen at eye level 5' away from the subject.

2. Ask the subject to identify the colors shown on the screen for 10 trails and record accuracy per color.

3. Repeat the process for distances of 10', 15', 20'.

4. At 20' distance, record reaction time per color in addition to accuracy data.

Appendix E: Client Feedback Survey

Client Feedback Survey

After using the balance device prototype with clients

Overall how did you like using the device compared to the existing device (yardstick)? *

	1	2	3	4	5	
More improvements needed	○	○	○	○	○	Loved it

On a scale from 1 to 5, how much did the weight of this device affect the usability? *

	1	2	3	4	5	
Extremely difficult to hold up for the length of exercise	○	○	○	○	○	Very easy to sustain the weight

How well were patients able to identify colors from the display? *

	1	2	3	4	5	
Difficult	○	○	○	○	○	Easy

Were there any colors in particular that patients had difficulty in identifying?

Your answer

How long on average was the device used per patient? (minutes) *

Your answer

How many times was the device used per day? *

Your answer

Would you like the screen size to be smaller, larger, or keep the size?

Your answer

Would you want the rod to be longer, shorter, or are you happy with the current size?

Your answer

How comfortable is it to hold the device for continued use? *

	1	2	3	4	5	
Could not stand to hold this device for very long at all	○	○	○	○	○	Could hold the device through the working hours

How easy was it to sanitize the device? *

	1	2	3	4	5	
Very awkward to sanitize, was unable to obtain a proper clean	○	○	○	○	○	Very easy, was able to achieve outstanding cleanliness

How effective was the extending and collapsing mechanism on the rod? *

	1	2	3	4	5	
Very difficult to adjust the length, required a lot of force	○	○	○	○	○	Very easy to use the mechanism

How intuitive is the device to use without prior training? *

	1	2	3	4	5	
I have no clue how this thing works!	○	○	○	○	○	I am able to effectively use this device the moment I pick it up.

How durable is the device? *

	1	2	3	4	5	
Broke, malfunctioning after a single use	○	○	○	○	○	Very durable, could withstand consistent up to 40 hours a week

How compatible is the device with the functional reach test? *

	1	2	3	4	5	
Extremely difficult to perform the test and was not effective	○	○	○	○	○	Was a perfect tool for this application

How did you find it to unscrew the cap of the display? *

	1	2	3	4	5	
Easy	○	○	○	○	○	Difficult

How convenient is it to turn the device's battery on and off in between uses? *

	1	2	3	4	5	
Hard and inconvenient, takes too much time and effort	○	○	○	○	○	Easy and convenient, doesn't take much time and doesn't cause delay in between uses

How sensitive is the button in signaling a color change?

	1	2	3	4	5	
Required many button presses to change color	○	○	○	○	○	Color changes immediately after pressing the button

What aspects did you enjoy about the device? *

Your answer

Please tell any improvements could be made to this device. *

Your answer

Any other thoughts, questions, concerns, comments, etc?

Your answer

Submit

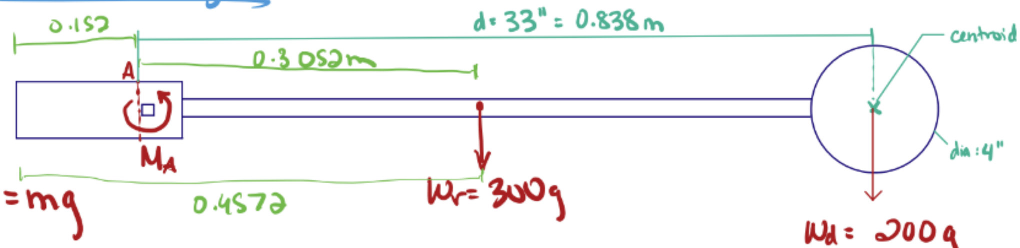
Clear form

Appendix F: Moment Calculations

distance bottom button to centroid case: 33"
d bottom button to bottom case: 31"

dia case: 4"

No counterweight



F = mg

$$F_{rod} = (0.3\ kg)(9.81\ m/s^2) = 2.943\ N$$

$$F_{disk} = (0.2\ kg)(9.81\ m/s^2) = 1.962\ N$$

$$\Sigma M_A = 0 = -(1.962\ N)(0.838\ m) - (2.943\ N)(0.3052\ m) + M_A$$

$$M_A = 2.542\ N \cdot m$$

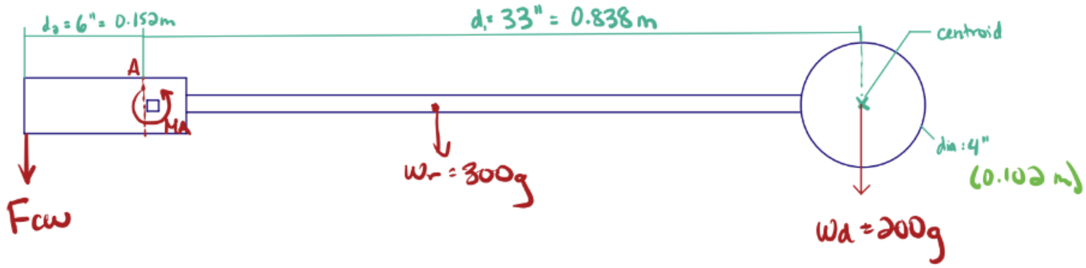
Battery pack weight

weight 1 AAA battery: 11.5 g

weight 4 AAA battery case: 44.742g

total: 4 x 11.5 + 44.742 = 90.742g

Counterweight (to minimize reaction moment)



$$\Sigma M_A = 0 \quad M_A - F_{rod}(0.3052m) - F_{disk}(0.838\ m) + F_{cw}(0.152\ m)$$

$$\boxed{M_A = 2.542\ N \cdot m - \underbrace{F_{cw}}_{W_{cw}(9.81)}(0.152\ m)}$$

F_{cw} = 16.7237 N when $M_A = 0$

$W_{cw} = 1.7048$ kg

moved battery – $W_{cw} = 90.792$ g, $W_{disk} = 109.208$ g

$M_A - 2.943(0.3052\text{ m}) - 1.0713(0.838) + 0.8907(0.152)$

$M_A = 1.66$ N·m → 34.67% less than battery in disk

$$\boxed{M_A = 1.66\text{ N·m} - \overbrace{F_w(0.152\text{m})}^{1.49\,W_{cw}}}$$

$F_w = 10.92$ N when $M_A = 0$

$W_{cw} = 1.11$ kg

$\frac{1}{2}$ extended rod (0.178) disk (0.546 m)

Norm

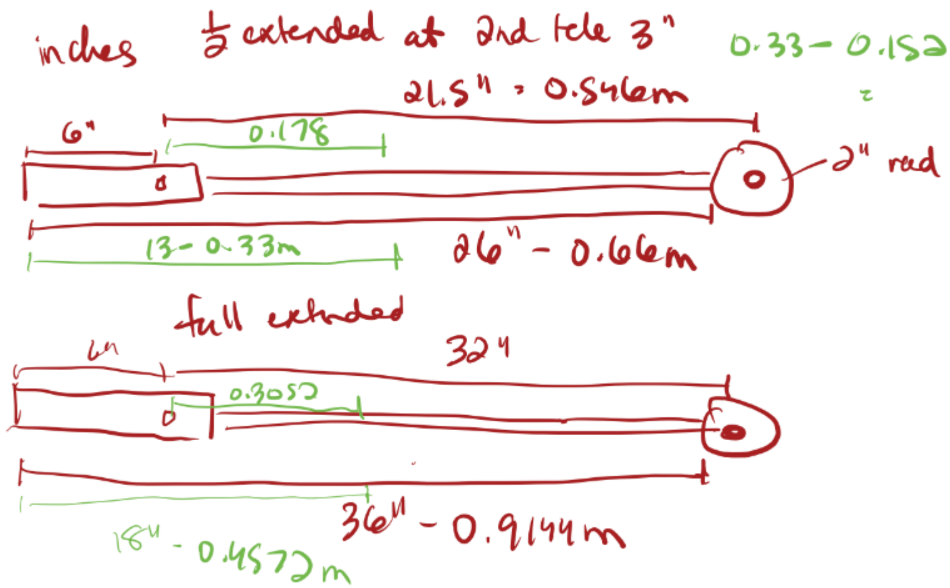
$M_A = 2.943\text{ N}(0.178) + 1.962(0.546) - W_{cw}(9.81)(0.152)$

$$\boxed{M_A = 1.595 - 1.49\,W_{cw}}$$

Moved battery

$M_A = 2.943(0.178) + 1.0713(0.546) - 1.49\,W_{cw} - 0.8907(0.152)$

$$\boxed{M_A = 0.9734 - 1.49\,W_{cw}}$$


inches
½ extended at 2nd tele 3"
0.33 - 0.152
21.5" = 0.546m
6"
0.178
2" rad
13 - 0.33m
26" - 0.66m
full extended
6"
32"
0.3052
36" - 0.9144m
18" - 0.4572m

Appendix G: Client Feedback Survey Results

Questions were shortened into Q1-Q10 in this table so that it is easier to view results in a readable format.

Table 2. Results of the Client Feedback Survey (survey taken by Mr. Daniel Kutschera).

Timestamp	11/29/2023 12:12:20
Overall how did you like using the device compared to the existing device (yardstick)?	3
On a scale from 1 to 5, how much did the weight of this device affect the usability?	2
How well were patients able to identify colors from the display?	3
Were there any colors in particular that patients had difficulty in identifying?	Colors were too small and off shades
How long on average was the device used per patient? (minutes)	10 minutes
How many times was the device used per day?	5
Would you like the screen size to be smaller, larger, or keep the size?	Larger
Would you want the rod to be longer, shorter, or are you happy with the current size?	Shorter - we didn't need the extra extension
How comfortable is it to hold the device for continued use?	1
How easy was it to sanitize the device?	5
How effective was the extending and collapsing mechanism on the rod?	2
How intuitive is the device to use without prior training?	4

How durable is the device?	5
How compatible is the device with the functional reach test?	2
How did you find it to unscrew the cap of the display?	4
How convenient is it to turn the device's battery on and off in between uses?	3
How sensitive is the button in signaling a color change?	1
What aspects did you enjoy about the device?	Patients enjoyed the colors. I liked having a more professional device to use. Easy to clean. Very intuitive once turned on.
Please tell any improvements could be made to this device.	Lighter head. Don't need the distal telescoping portion. Measuring hash marks on top and beginning at the proximal end. Larger visual display. Obvious primary colors. Shapes. Less glitchy switch. External on/off. One therapist suggested a noise feature when the screen was tapped to let the pt know they touched the target.
Any other thoughts, questions, concerns, comments, etc?	Overall the device was a fantastic first attempt. The therapists were really excited to have such a device. The weight was the largest complaint.