

# **Lerner Robotic Arm**

## **Finalized Testing Plan Report**

**Cole Pace: Project Manager and Prototype Lead**

**Joel Gisleskog: Research Lead**

**Caleb Lamca: Manufacturing Lead, Co Design Lead, and  
Fundraising Lead**

**Kaitlyn Davis: Finance Lead and Documentation Lead**

**Colin Donnellan: Development Lead, Co Design Lead, and  
Testing Lead**

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Steve Sanghi College of Engineering

**Project Sponsor: Dr Zachary Lerner**

**Faculty Advisor: Dr. Dante Archangeli**

**Instructor: Dr David Willy**

## Introduction

The objective of the team is to create a hip mounted robotic arm that will focus on upper limb rehabilitation of stroke survivors. As the belt is nearing completion of its build with minor changes being made, the testing plan starts to become clear. This report will further detail the requirements of the project as they have been updated through the projects life and how the device will be tested to make sure the device meets the requirements that have been outlined.

## Design Requirements Summary

Through our design requirements given for the project and will be detailed below

- Customer Requirement 1 (CR1): Comfortable for users to wear
  - The device will be worn by people and should be comfortable for the user to wear.
- Customer Requirement 2 (CR2): Ability to Sit in Chairs
  - Since the device would be worn in a day-to-day life capacity, it will need to be able to sit in chairs.
- Customer Requirement 3 (CR3): Low Profile
  - The device needs to be low profile for minimal obstruction for public use
- Customer Requirement 4 (CR4): Accessibility of the Design
  - The device should be able to be 3D printed so that it can be put on OpenExo.
- Customer Requirement 5 (CR5): Durability
  - The device should be able to be used repeatedly without mechanical fail as well as not be able to be easily damaged in what would be everyday life
- Engineering Requirement 1 (ER1): 3 Degrees of freedom
  - The device needs 3 degrees of freedom to be able to assist the arm of the user
- Engineering Requirement 2 (ER2): Weight of Arm
  - The arm before attached to the apparatus that the user will wear should be under 2 kg.
- Engineering Requirement 3 (ER3): Speed of Arm
  - The motors of the arm should be able to reach a minimum of 10 rpm.
- Engineering Requirement 4 (ER4): Battery Life
  - Through more research and deliberation, the battery is the biggest limitation of the device, so a goal of 30 minutes is more attainable than the previously desired time.

- Engineering Requirement 5 (ER5): Manufacturing Cost
  - The cost of material and manufacturing should be less than \$2000 to keep the device affordable.

## Top Level Testing Summary

Table 1: Test Summary Table

Experiment/Test	Relevant DRs	Testing Equipment Needed	Other Requirements
Endurance Test	ER4-Battery Life	Device A User Battery Timer Camera	Battery is fully charged
Range Test	ER1-Degrees of Freedom	Device A User Camera	N/A
Weight Test	ER2-Weight of Arm	Scale Device Camera	The device will be disassembled so that the arm is being weighed by itself
Comfortability Test	CR1-Comfortability CR3-Low Profile ER2- Weight of Arm	Device Multiple Users Camera	N/A
Chair Test	CR1- Comfortability CR2-Ability to Sit CR3-Low Profile	Multiple Chairs Multiple Users Device Camera	N/A
Controller Test	ER1-Degrees of Freedom	Device User Camera Timer	Ability to read sensors
Speed Test	ER3- Speed of Arm	Device User Camera Timer	Average time it takes to lift an arm.
Bump Test	CR5-Durability CR3-Low Profile	Device Camera	N/A

## Detailed testing Plans

### Endurance Test

Summary:

The test will answer the question of how long the battery will last in the device.

The design requirement that this will be testing is ER4, which is battery life. The variable that will be tested is the battery itself to see how long it will last while powering the two motors. The battery will consistently be at full charge to see how long a full battery can last in the device.

Procedures:

1. Make sure Battery is fully charged
2. Have correct command on the motors so that it is constantly spinning at a safe speed.
3. Connect all components to the board to control the start time of the test.
4. Start timer when it is switched on to record how long it will last.
5. Repeat to make sure results are consistent.

Results:

The results that are expected are to be around 30 minutes. This is slightly better than what was calculated as one battery can power both motors for about 25 minutes in the calculation. This was also calculated at the highest speed, which may not be used in the actual control algorithm. The time goal has also been informed to us by NAU's Biomechatronic lab that uses the same battery and has gotten comparable results.

Conclusion:

This test will validate that the battery system meets the minimum 30-minute operational requirement (ER4), confirming sufficient duration for clinical rehabilitation sessions. Achieving this benchmark ensures the device is practical for real-world therapeutic use without frequent recharging interruptions.

## **Range Test**

Summary:

The test will answer the question of how many degrees of freedom the device has. This will be testing ER1, the degrees of freedom, so that the entire range of motion desired for the device has been reached. There is not much equipment needed, so it will just be the device itself and a user to wear it and test it. The isolated variable would be the device itself as no changes would be made while the user tests it.

Procedures:

1. Have the user put on device and be fully strapped in.
2. Make sure the device is not turned on as electrical components are not being tested.
3. Have the user move arm to make sure the device can follow it to make sure the degrees of freedom are reached.

Results:

The result that is expected is that it will reach the 3 degrees of freedom required by the device. The design was made specifically to reach and have all degrees of freedom. The device will have two active and one passive degree of freedom.

Conclusion:

This test confirms that the device achieves the required 3 Degrees of Freedom (ER1), validating the mechanical design's ability to accommodate natural arm movement. Successfully demonstrating 2 active and 1 passive DOF ensures the arm can follow the user's intended motion paths during rehabilitation exercises.

## **Weight Test**

Summary:

The test will answer the question of how heavy the device is. The design requirement that this will be testing is ER2, which is weight of arm. The variable that will be tested is the arm part of the device to see how heavy the arm is as that will be the biggest weight on the user. The arm will be separated from the rig that is worn by the user to get true weight of the arm.

Procedures:

1. Have the arm separated from the wearable rig.
2. Lay device on scale to record weight.

Results:

The results that are expected are to be under 2 kg. This was a critical design requirement as the device will be used by stroke survivors, so the device cannot be heavy to impede in their rehabilitation.

Conclusion:

This verification ensures the robotic arm assembly remains under the 2 kg threshold (ER2), critical for preventing user fatigue and additional strain on stroke survivors. Meeting this requirement validates the material selection (carbon fiber/onyx) and design choices aimed at minimizing distal weight.

## **Comfortability Test**

Summary:

The test will answer the question of whether the entire design is comfortable to wear. The design requirements that this will be testing are CR1, comfortability, CR3, low profile, and ER2, weight of the arm. The variable that will be tested is the device itself to see if a user would be comfortable wearing it. The device will not be changed through testing with different users.

Procedures:

1. Have users put the device on.
2. Have user give feedback on how they feel in device
3. Repeat with multiple different users.

Results:

The result that is expected is that it will be comfortable to wear. Throughout the design process of the device, the team had a focus on having the device be comfortable in where it interacts with the users.

Conclusion:

User feedback from this assessment will confirm whether the device meets comfort (CR1) and low-profile (CR3) requirements during extended wear. Positive results will indicate that the harness design and weight distribution are acceptable for daily use by the target patient population.

## **Chair Test**

Summary:

The test will answer the question of whether the user can sit in chairs while wearing the device. The design requirements that this will be testing are CR1, comfortability, CR2, ability to sit, and CR3, low profile. The variable that will be tested is the full device to meet the client's demand of ability to sit in chairs. The device will not be changed while different chairs are tested.

Procedures:

1. Have the user put device on
2. Have user sit in chair
3. Have user give feedback on if they are comfortable
4. Repeat with several types of chairs

Results:

The results that are expected are that the user will be able to comfortably sit in a chair while wearing the device. This might vary from user to user, but we will be testing with one user. The device can be adjusted to the location of the arm that can determine how well they can sit in several types of chairs.

Conclusion:

Successful completion demonstrates that the hip-mounted design allows users to sit comfortably in various chair types (CR2), validating the low-profile form factor essential for real-world adoption. This confirms that the device does not impede basic daily activities like sitting in standard furniture.

## **Controller Test**

Summary:

The test will test if the controller can have the motor move with input from a sensor. The design requirement that this will be testing is ER1, the degrees of freedom. The variable that will be tested is the device to see if it will move with reading a sensor. The motor will be the same throughout the testing of it.

Procedures:

1. Have all software uploaded to the board
2. Connect all components to the board
3. Have force on FSR to make sure a reading is being made
4. Start test to see if motor reacts in the desired way when FSR has a reading.

Results:

The result that is expected is that the control code will work. This will be a test of

how well the previous code that is being used by OpenExo can be adjusted to fit this device.

Conclusion:

This validation ensures the sensor-to-motor control loop functions correctly, confirming that the FSR input successfully drives motor response for the required degrees of freedom (ER1). Successful integration proves that the software architecture can support the intended assistive functionality.

## Speed Test

Summary:

The test will answer the question is the speed of the arm. The design requirement that this will be testing is ER3, which is the speed of the arm. The variable that will be tested is the motor to see if it is fast enough to raise the user's arm. The battery will consistently be at full charge to see how fast a motor is receiving full power. The variables that will need to be calculate is the speed using the time it took and the distance of the final

Procedures:

1. Make sure Battery is fully charged
2. Have user put on device
3. Connect all components to the board to control the start time of the test.
4. Start timer to see how long it takes to lift their arm.
5. Repeat to be able to calculate the speed.

Results:

The result is expected to be able to reach a speed of 10 rpm. The rated speed of the motor given in its specifications is 40 rpm, so it will be able to make that speed. Through the calculation of an average time to raise an arm from 0 to 90 degrees it took 1.28 seconds which means the speed it needs to be is 11.72 rpm which is below the rated speed of the motor.

$$\omega_{avg} = \frac{\Delta\theta}{t} = \frac{90^\circ \cdot \left(\frac{\pi}{180}\right)}{1.28s} = 1.227 \frac{rad}{s}$$

$$v = \omega_{avg} \cdot r = 1.227 \frac{rad}{s} \cdot 0.33m = 0.405 \frac{m}{s}$$
$$v = 0.405 \frac{m}{s} \cdot \frac{60}{2\pi r} = 0.405 \frac{m}{s} \cdot \frac{60}{2\pi(0.33)} \approx 11.72 rpm$$

Conclusion:

Timing verification will confirm that the motors achieve the minimum 10 RPM specification (ER3), ensuring the arm moves fast enough to provide natural assistance during lifting motions. Meeting the calculated 11.72 RPM requirement validates that the motor selection is adequate for therapeutic use.

## Bump Test

Summary:

The test will answer the question of how strong the device is. The design requirements that this will be testing are CR5, which is durability, and CR3, which is low profile. The variable that will be tested is the arm itself on the full device. The arm will be consistently on the same side as well as the being strapped to the user the entire time.

Procedures:

1. Have the user put the full device on.
2. Have user bump into tables, walls, and other objects to mimic real life possibility of running into things
3. Observe if there are any cracks or defects from the test
4. Run motors to see if those were affected at all

Results:

The result that is expected is that the device will be able to withstand the possible bumps of life due to the strength of the onyx and carbon fiber that it is made with. The motors should not be affected due to the design stopping outside materials from hitting the motor.

Conclusion:

Durability testing will confirm that the device can withstand incidental contact with environmental obstacles (CR5) without mechanical or electrical failure. This validates the robustness of the Onyx/carbon fiber construction and protective housing design for everyday wear.

# Specification Sheet Preparation

Table 2: CR Summary Table

Customer Requirement	CR Met?	Client Acceptable?
CR1-Comforbility		
CR2- Ability to sit in chairs		
CR3-Low profile		
CR4-Accessibility of Design		
CR5- Durability		

Table 3: ER Summary Table

Engineering Requirement	Target	Tolerance	Measured/ Calculated Value	ER Met?	Client Acceptable?
ER1-Degrees of Freedom	3	±0			
ER2-Weight of Arm	<2 kg	+ 0.25 kg			
ER3-Speed of Arm	≥10 RPM	- 2 RPM			
ER4-Battery Life	30 min	± 5 min			
ER5-Manufacturing Cost	\$2000	± \$250			

## QFD

This Quality Function Deployment (QFD) chart shows how what users want connects to the technical specs we need to test. It links the five main customer needs including comfort, ability to sit in a chair, accessibility, durability, and low profile to our engineering targets like degrees of freedom, cost, speed, battery life, and weight. The numbers in the matrix show which engineering features matter most for each user's needs, so we know what to focus on during testing. This helps us make sure our testing plan covers both what the users care about and our technical goals, such as keeping the device

under 2 kg and ensuring the battery lasts more than 30 minutes.

		Degrees of Freedom				
		Manufacturing Cost	neg			
		Speed of Arm	neg	neg		
		Battery Life	neg	neg	pos	
		Weight	neg	pos	pos	pos
		Engineering Requirements				
Relative Weight (%)	Customer Weights	Customer Requirements	Degrees of Freedom	Manufacturing Cost	Speed	Battery Life
11	4	Comfortable	3	1	3	3
22	5	Ability to Sit in a Chair	9	1	1	1
10	2	Accessibility	3	9	3	3
5	3	Durability	1	1	1	1
22	3	Low-Profile	3	3	3	9
		Technical Requirement Units	N/A	\$	rpm	Minutes
		Technical Requirement Targets	3	<2000	>10	>30
			kg	<2		

Figure 1: Quality Function Deployment (QFD) Chart

Positive	pos	Strong	9
Negative	neg	Moderate	3
		Weak	1

Figure 2: Labels for QFD

## Conclusion

The testing plan in this report provides a full validation framework for the Lerner Robotic Arm, ensuring compliance with all specified customer and engineering requirements. By systematically verifying battery endurance, mechanical range, weight constraints, user comfort, durability, and control functionality, these tests will demonstrate that the device is ready for deployment as a viable upper-limb rehabilitation tool for stroke survivors. Successful completion of this testing protocol will confirm that the design balances technical performance with practical usability, meeting both the clinical needs of users

and the manufacturing constraints of the OpenExo platform.