Project 3

EMG biofeedback device for Brachial Plexus Injury Rehabilitation

Submitted in partial fulfillment of the requirements of the degree of Master of Design by -

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Interaction Design
M. Des. (2017–2019)

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Approval Sheet

The Interaction design project III entitled "EMG biofeedback device for Brachial Plexus Injury Rehabilitation" by Angela R. Simon, roll number-176330010 is approved, in partial fulfillment of the Masters in Design Degree in Interaction Design at IDC School of Design, Indian Institute of Technology, Bombay.

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I declare that this written document represents my ideas in my own words, and where other's ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented of fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have this not been properly cited or from whom proper permission has not been taken when needed.

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Acknowledgment

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Finally, I would like to thank my classmates for all their help and support and my parents for their constant support.

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Motivation

The need for a cost-effective biofeedback solution was identified by Dr Chhaya Verma, HOD-Physiotherapy Department at Nair Hospital. From her experience as a physiotherapist working with BPI patients, Dr Chhaya told us about the challenges that both the therapists and BPI patients face during the rehabilitation. She highlighted the rise in Brachial plexus injuries amongst adults and youth due to motor accidents. Aware of the effectiveness of biofeedback for muscle re-education, she wishes to use the technology for her patients. A multipurpose biofeedback device was purchased by the centre but it wasn't used much after it had a technical issue. Also, it wasn't fixed either because it was barely used by anyone due to its complexity. Spending on a device that hasn't be used to its fullest can be questionable in a govt. setup where budgets have a tight constraint. Most of her patients come from places away from the city and tend to spend months in the city for the treatment. This puts a strain on their finances and patients tend to leave the treatment as soon as little improvement is seen. Dr Chhaya was looking for a biofeedback solution that is easy to use, cost-effective and can also be used by the patients in their home program.

1. Abstract

Biofeedback devices are used commonly by physiotherapists for the rehabilitation treatment of a wide range of neuromuscular and musculoskeletal problems. Physiotherapy centres in India purchase imported biofeedback units which come packed with multiple features for electrostimulation, EMG biofeedback, pressure biofeedback etc. This makes the devices multi-purpose and expensive. Cost of such devices and their complex usability limits their usage to therapy centres and trained therapists. In this design project, we looked into the use of biofeedback for Brachial Plexus Injury (BPI) rehabilitation. Biofeedback is used primarily for muscle re-education after nerve transfer surgery in BPI treatment. Considering the ecosystem of a govt physiotherapy centre that specialises in BPI rehabilitation, we identified the challenges they face in providing the best results to their BPI patients. This design project presents a cost-effective sEMG biofeedback solution that is simple to use and specific to BPI rehabilitation. Eliminating use of dedicated hardware for displaying biofeedback signals and using a smartphone app instead reduces the cost of the system. The solution includes sEMG sensor units along with an accompanying mobile application that can be used by both physiotherapists and BPI patients. Expert evaluation on the design of the system and the mobile app was carried out at the end of the project.

Table of Content

1. Introduction

We identified the therapists to be our first user and the patients to be our second set of users. While the patient is the one affected, it is the therapist who makes major decisions for recovery of a patient in BPI rehabilitation. In order to design BPI rehabilitation, it was important to first understand the therapist side knowledge of BPI rehabilitation and study the different factors that help in decision making during the course of rehabilitation. This section consists of a compilation of all the literature review on clinical and physiological aspects of Brachial Plexus Injury -

3.1. The Brachial Plexus - Anatomy and Physiology
3.2. Brachial Plexus Injury
3.3. BPI treatment by Nerve transfer s

1.1. Brachial Plexus anatomy and physiology

Brachial Plexus (Fig. 1) is a complex network of nerves [1] that extends from the spinal cord at the neck to the shoulder and the arm through the axilla (armpit).

The brachial plexus is responsible for cutaneous and muscular innervation of the entire upper limb.

The plexus consists of roots, trunks, divisions, cords and branches.

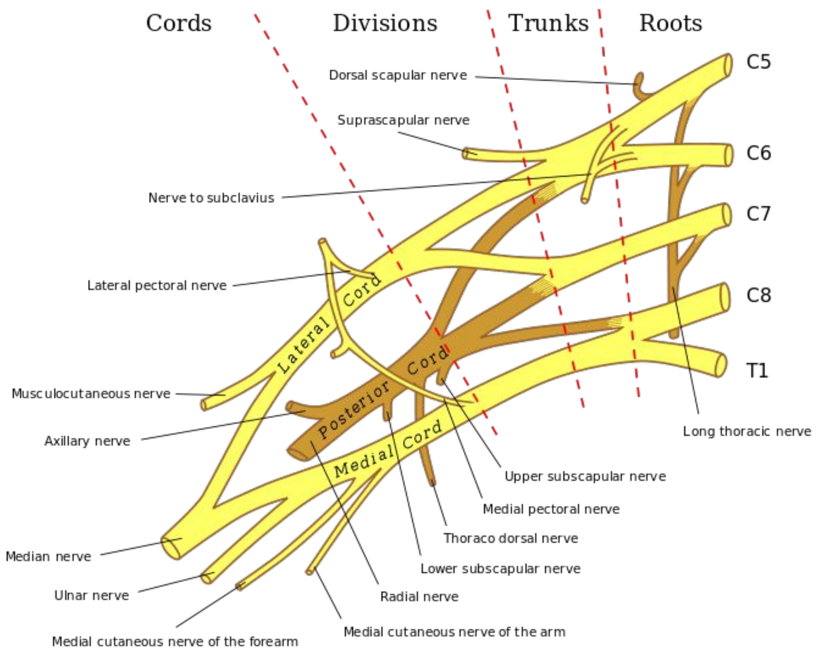


Image 1: Brachial Plexus

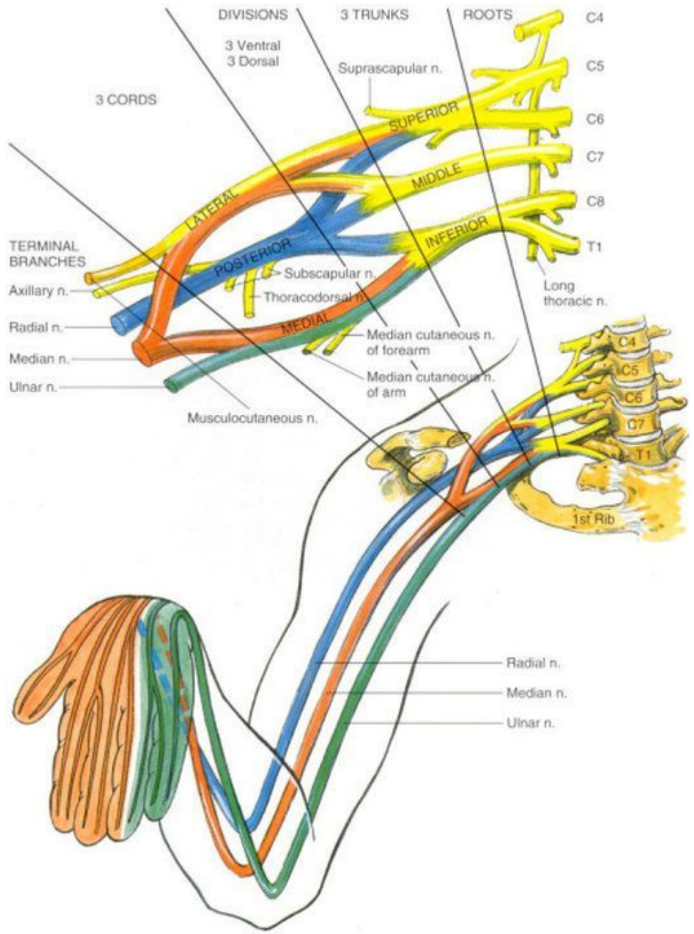
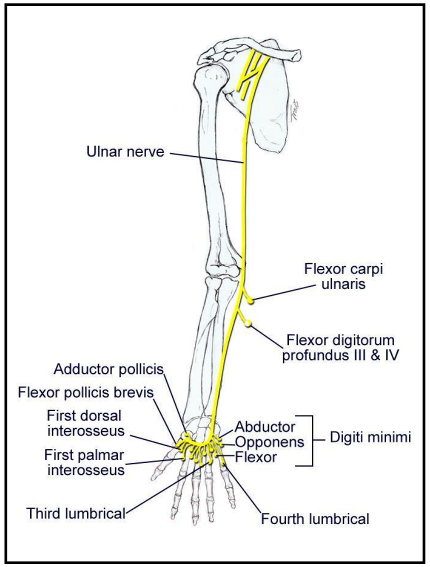


Image 2: Brachial Plexus between shoulder and neck

5 Major nerve innervations of the Brachial Plexus branches –

1) Ulnar nerve, 2) Musculocutaneous nerve, 3) Axillary and Radial nerve, 4)Median nerve.



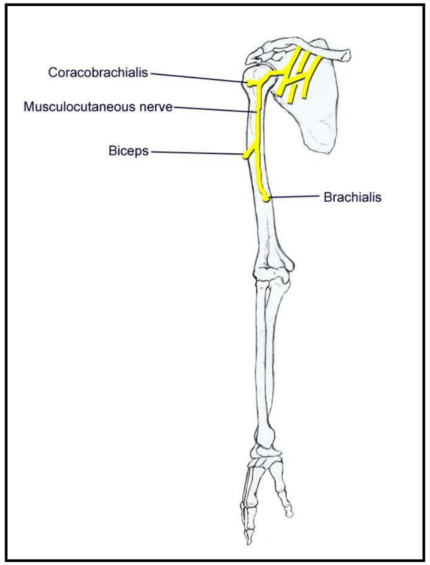
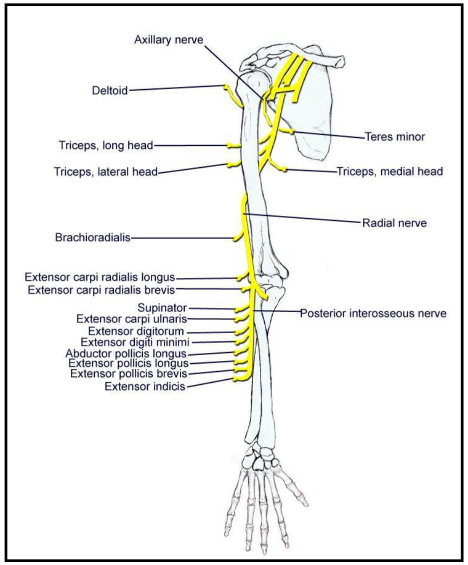


Image 3: *Ulnar nerve (left)*

Image 4: *Musculocutaneous nerve (right)*



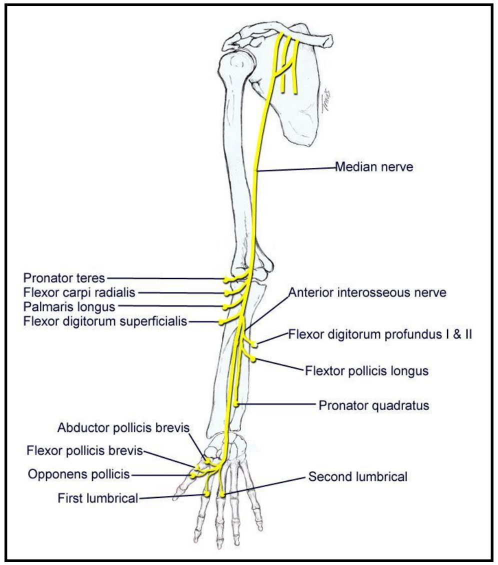


Image 5: Axillary and Radial nerve (left)

Image 6: Median nerve (right)

1.2. Brachial Plexus Injury

A person can injure the Brachial Plexus in automobile accidents, sports accidents, other accidents or due to some medical condition.

BPI can be of varying severity [2].

Avulsion - The nerve root is torn off from the spinal cord and may not be repairable with surgery.

Stretch - Nerve is mildly stretched and may heal on its own without surgical intervention.

Rupture - The nerve is torn partially or fully due to a forceful stretch. Hand function can be surgically restored by nerve transfer.

The effects of a minor BPI are paralysis of shoulder and elbow with the hand functions still preserved. A major BPI which involves torn brachial plexus would leave the arm paralysed, lost of all its functions.

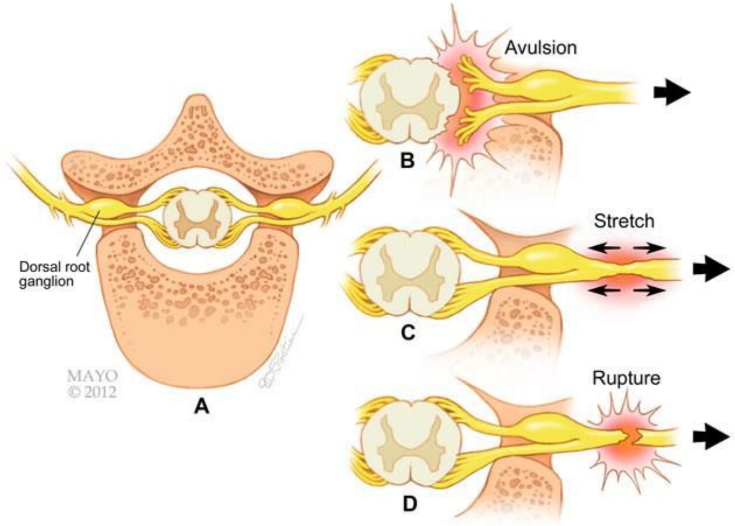


Image 7: BPI due to Motor accidents

Image 8: Degrees of Injury (top)
Image 9: BPI due to sudden trauma at the shoulder joint

Image 10: BPI patient with injured right arm.

! Media has been captured and displayed with patient's and therapist's consent.

1.3. BPI Treatment with nerve transfer surgery

Nerve transfer surgery is carried out to replace the injured nerves with less essential nerves from other parts of the body. This helps in restoring the lost function with the help of a substitute nerve.

The injured nerve and the muscle it innervates are called the recipient nerve and the recipient muscle. The healthy transfer nerve and the muscle it innervates are called the donor nerve and the donor muscle.

Table 1 lists some common Upper Limb nerve transfers are listed by Hill et al. [4]

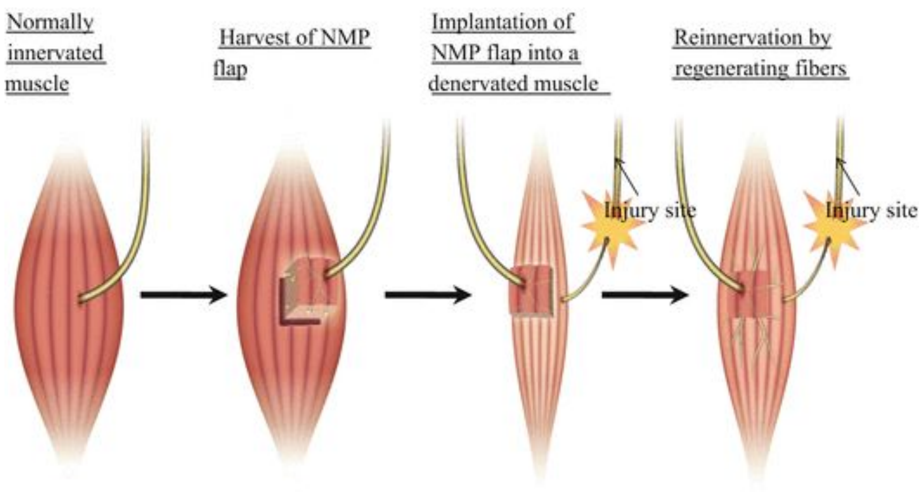


Image 11: Nerve transfer surgery © Springer. Eiji Yumoto: Denervation and Reinnervation of the Thyroarytenoid Muscle

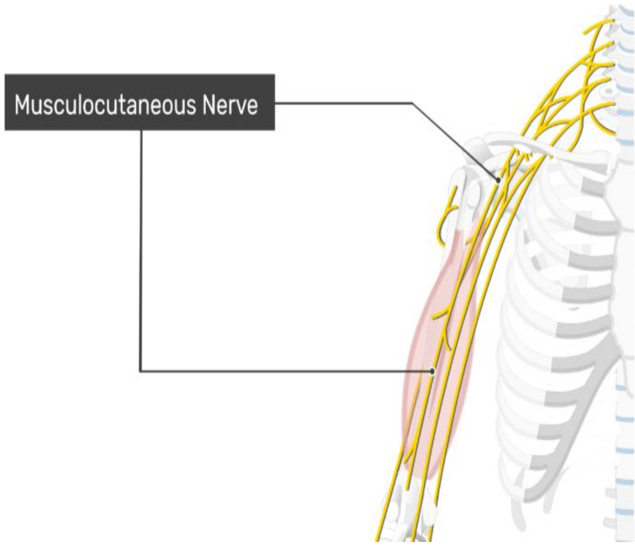
Table 1: Common upper limb motor nerve transfers

Nerve transfer	Indication	Donor nerve	Recipient nerve	Function restored	Months to muscle tenderness	Months to visible muscle contraction	Months to functional movement	Percentage of patients achieving useful motor function
Anterior XI to SSN	C5 avulsion or rupture	Lateral branch XI	SSN	Shoulder abduction and external rotation	4	8	12-14	70
Posterior XI to SSN	C5 avulsion or rupture plus suspected concomitant injury to SSN at the supra scapular notch	Medial branch XI	SSN	Shoulder abduction and external rotation	3	6	12	80
Upper trunk to XI	Irreparable injury to upper XI	Posterior division upper trunk	XI	Scapula and shoulder girdle elevation; medicalisation of the scapula	4	8	12-14	75
Somsak	C5 avulsion or rupture; axillary nerve injury	Long head of triceps	Anterior division of axillary nerve	Shoulder abduction	3	6	12	80
Modified somsak	C5 avulsion or rupture; axillary nerve injury; motor radiculopathy C5	Medial head of triceps	Anterior division of axillary nerve; anterior and posterior divisions of axillary nerve	Shoulder abduction; shoulder abduction and external rotation	3	6	9-12	80
FCU ulnar nerve fascicle to axillary nerve	C5, 6 and 7 root injury, posterior cord injury	FCU fascicle ulnar nerve	Anterior division of the axillary nerve	Shoulder abduction	4	8	12-14	70
Oberlin 1	C5 and C6 avulsion; upper trunk rupture; musculocutaneous nerve injury	FCU fascicle ulnar nerve	Motor branch to biceps	Elbow flexion	3	4	12	80
Oberlin 2	Musculocutaneous nerve injury with anticipated re-innervation of biceps	FCR fascicle median nerve	Motor branch to brachialis	Elbow flexion	3	4	12	80
Modified double Oberlin	C5 and C6 avulsion; upper trunk rupture; musculocutaneous nerve injury	FCU fascicle ulnar nerve and fascicle median nerve	Motor branch to biceps and motor branch to brachialis	Elbow flexion	3	4	9	90
Medial pectoral to musculocutaneous	C5 and C6 avulsion; upper trunk rupture	Medial pectoral nerve	Musculocutaneous nerve	Elbow flexion	6	9	14-18	70
Intercostal nerves to triceps	C5,6 and 7 injury	Intercostals 3, 4 and 5	Motor branch to long head of triceps	Elbow extension	6	9	18-24	60
Thoracodorsal branch to long head of triceps	Posterior cord injury distal to thoracodorsal nerve	Medial branch thoracodorsal nerve	Long head of triceps	Elbow extension	4	9	12	75
Teres minor to long head of triceps nerve	Tetraplegic C5/6 injury	Nerve to teres minor	Nerve to the long head of triceps	Elbow extension	6	9	18	75
Thoracodorsal to long thoracic nerve	Isolated long thoracic palsy; C5,6 and 7 root injury as part of reconstruction	Lateral branch of the thoracodoral nerve	Long thoracic nerve	Scapula stabilisation	4	6	12	80

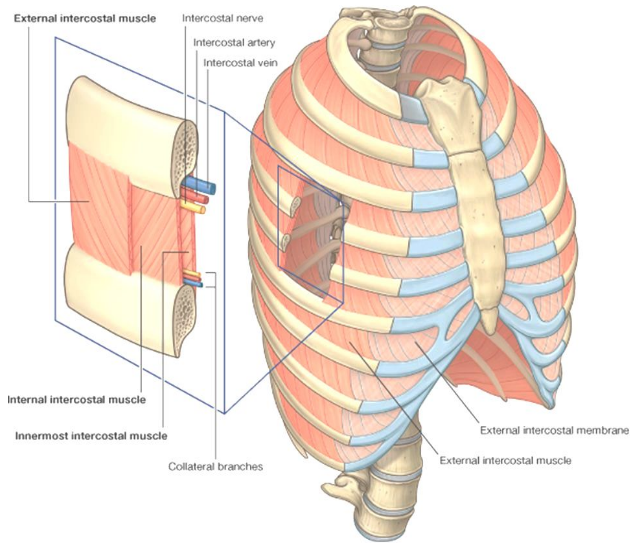
Image 12: Common Nerve transfer surgeries by Hill et. al.

For. eg. ICN to MCN nerve transfer.

When BPI affects the musculocutaneous nerve(MCN), the biceps loss their function of elbow flexion. In order to restore this function, one type of nerve transfer involves transferring a fascicle of 4th and 5th intercostal nerves(ICN) that are located between the ribs of the chest. The ICN nerves which are responsible for chest expansion during breathing will now help the biceps for elbow flexion.



Recipient



Donor

Image 13: Recipient and Donor muscle for ICN to MCN nerve transfer
© Elsevier. Drake et al: Gray's Anatomy for students - www.studentconsult.com
© GetBodySmart - Biceps Brachii - www.getbodysmart.com

1.4. BPI Rehabilitation post surgery

BPI rehabilitation post surgery is focused on regaining lost muscle function. This is done in number stages.

Firstly, the therapist looks for success of the nerve transfer. This is indicated by successful innervation of the recipient muscle by the donor nerve. Innervation is diagnosed using nerve conduction and electrotherapy.

Next the therapist starts stimulating the brain functions of the patient to form new neural paths that calls the donor nerve to do recipient action. Cognitive training techniques like - Bilateral Transfer of learning, Bilateral Muscle Contractions of Recipient and Donor muscles and Graded Motor Imagery are used.

To further assist the patient, therapists use electrotherapy to provide electrical stimulation to the recipient muscle during the exercises.This is to help the patient contract the recipient muscle as they still don't have voluntary control over it.

First signs of voluntary control is shown by very light muscle twitches. At this point the therapists gradually allow the patient to do the exercises without the help of electrical stimulation.

Repetition is a key factor in muscle re-education program. It helps strengthen the new neural paths as well as strengthen the recipient muscles which had remained unused due to the injury.

Pre- and post-surgical functional ability assessments are important for monitoring functional recovery and evaluating the effectiveness of treatments. Range of motion and strength are two common metrics used to assess functional ability.

Range of motion is assessed by making the patient perform a simple movement in a particular direction until the patient can no longer continue moving their limb in that direction. Strength is assessed using the BMRC scale.

The severity of muscle weakness can be classified into different BMRC "grades" based on the following criteria [4]—

Grade 0: No contraction or muscle movement.
Grade 1: Trace of contraction, but no movement at the joint.
Grade 2: Movement at the joint with gravity eliminated.
Grade 3: Movement against gravity with no added resistance.
Grade 4: Movement against gravity with mild resistance.
Grade 5: Normal strength, movement against gravity with complete resistance.

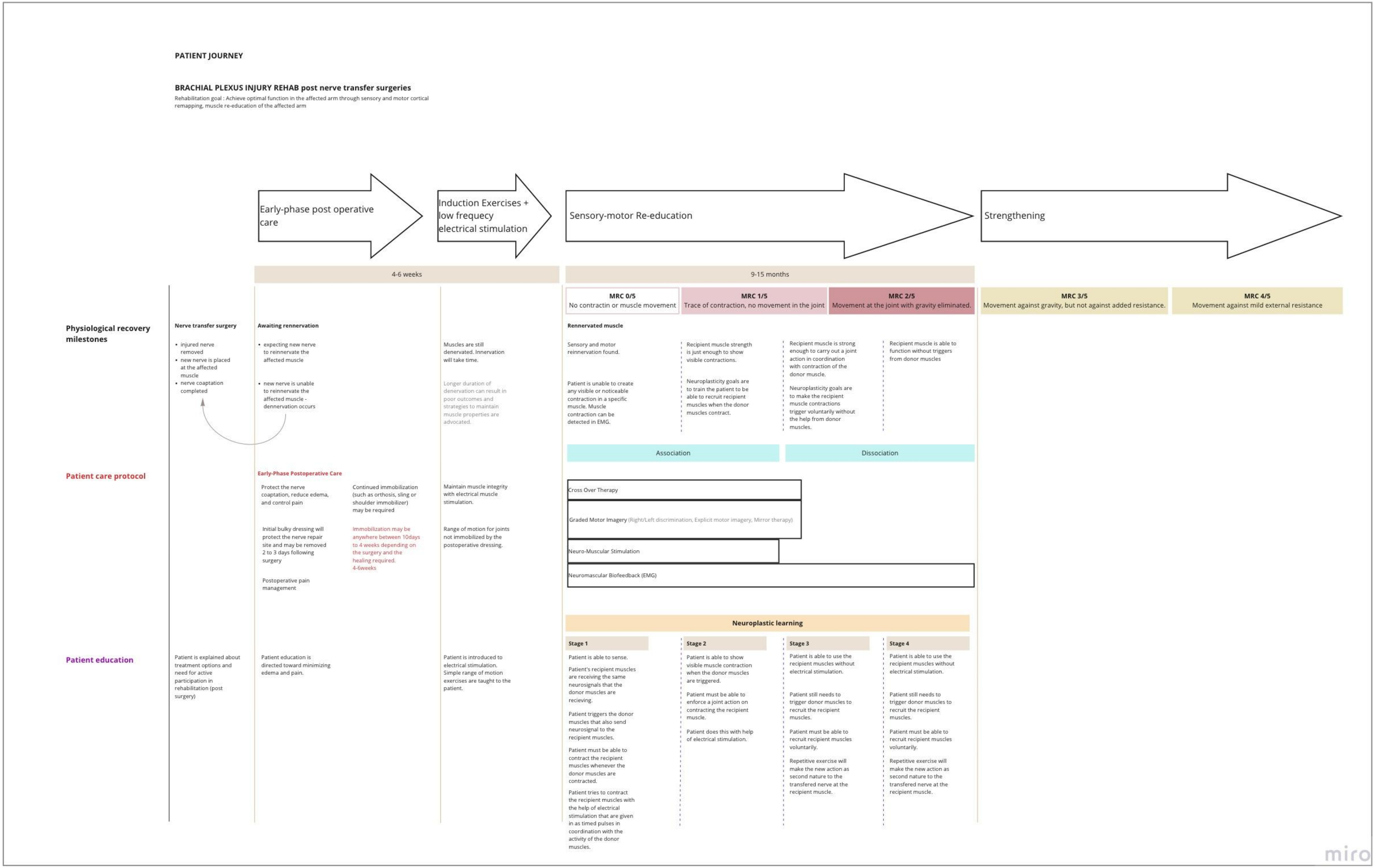
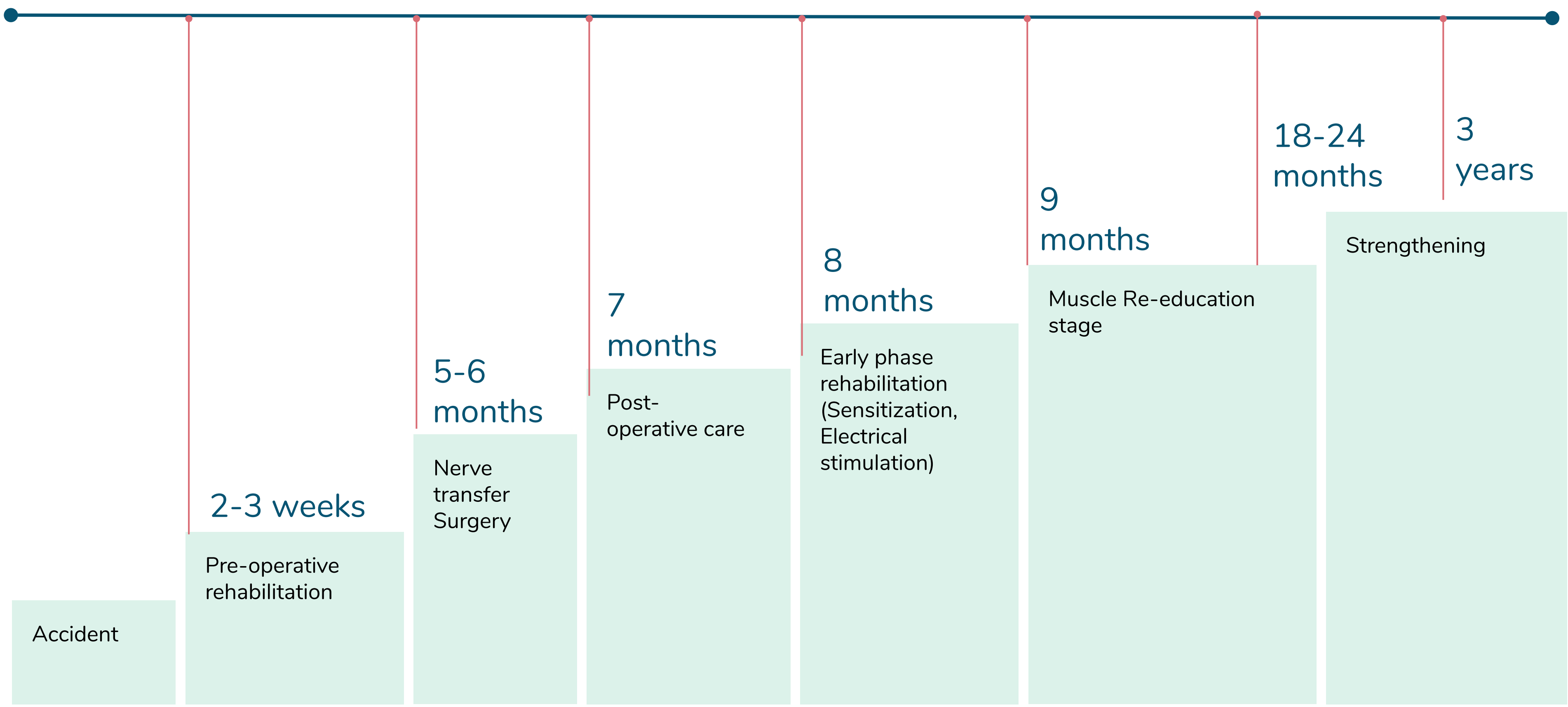


Diagram 1: Rehabilitation journey of a BPI Patient


Accident
2-3 weeks
Pre-operative rehabilitation
5-6 months
Nerve transfer Surgery
7 months
Post-operative care
8 months
Early phase rehabilitation (Sensitization, Electrical stimulation)
9 months
Muscle Re-education stage
18-24 months
3 years
Strengthening

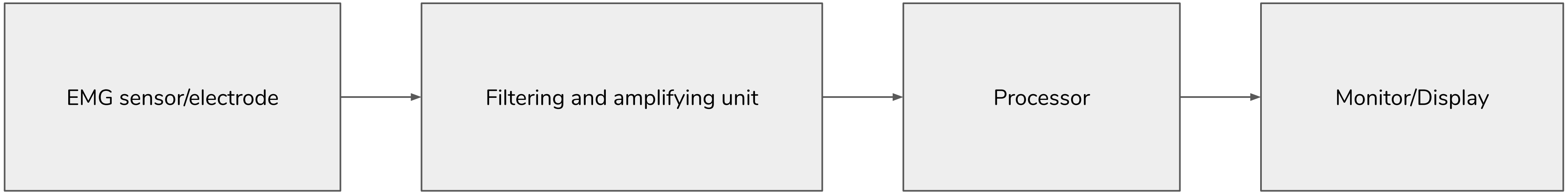
2. Biofeedback for Muscle re-education

Electromyography (EMG) is a method of recording and quantifying the electrical activity of the activated motor units within muscle fibres. EMG biofeedback has been successfully been applied as an adjunct to treatment of many neuromuscular and musculoskeletal problems. This section covers the basics of how electromyography works, use of muscular biofeedback for muscle re-education and the various devices in the market that help physiotherapists to train their patients.

2.1. How electromyography works?

Electromyography is used to record muscular activity. It is based on the fact that whenever the muscle contracts, negative voltage or action potential travels along the cell membrane. This can be detected and measured.

A simple biofeedback unit consists of sensors that pick up these signals from the muscles, filters and amplifies them, converts the signals from analog to digital and then displays it on a monitor.



Signals from the muscles can be acquired using two types of EMG electrodes. Surface EMG electrodes which are patches that can be applied on the skin surface above the muscles and needle electrodes which are pierced into the muscle body. For basic biofeedback applications, sEMG electrodes are sufficient. Needle electrodes are used to for more accurate clinical and diagnostic purposes.

Image 13: Surface EMG

Image 14: Needle EMG

2.2. Motor-neuron re-learning: Association and Dissociation

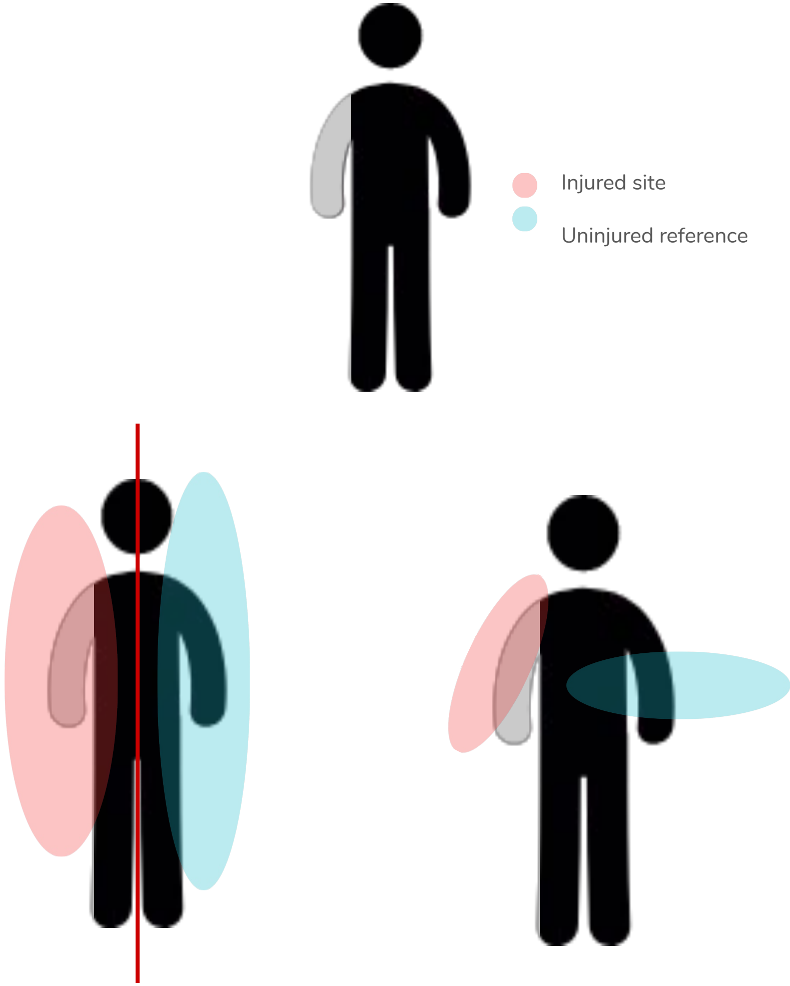
At the first signs of successful innervation, the therapists start training their patients with repetitive exercises.This helps in forming new neural paths in the brain. Some techniques are -

1. Graded Motor Imagery: The injured arm is hidden behind a mirror while the patient moves the healthy arm in symmetrical patterns in front of the mirror. The reflection of the healthy arm helps the patient to have a new awareness of both the arms. The brain starts actively mapping new neural paths.
2. Bilateral transfer of learning: Both the healthy arm and the injured arm are made to do range of motion exercises together.
3. Bilateral muscle contractions of Donor and recipient muscles: At a certain stage of recovery, the recipient muscle gets triggered whenever the donor muscles are activated. This happens because both the muscles are innervated by the common donor nerve. To further strengthen the recipient muscles, exercises that contract both the donor and recipient muscles together are taught to the patient.

There are two main stages of progress in this -

a. Association: When the patient is able to carry out the recipient muscle action while triggering donor muscle action
b. Dissociation: When the patient is independently able to carry out recipient muscle action without the help of the donor muscles.

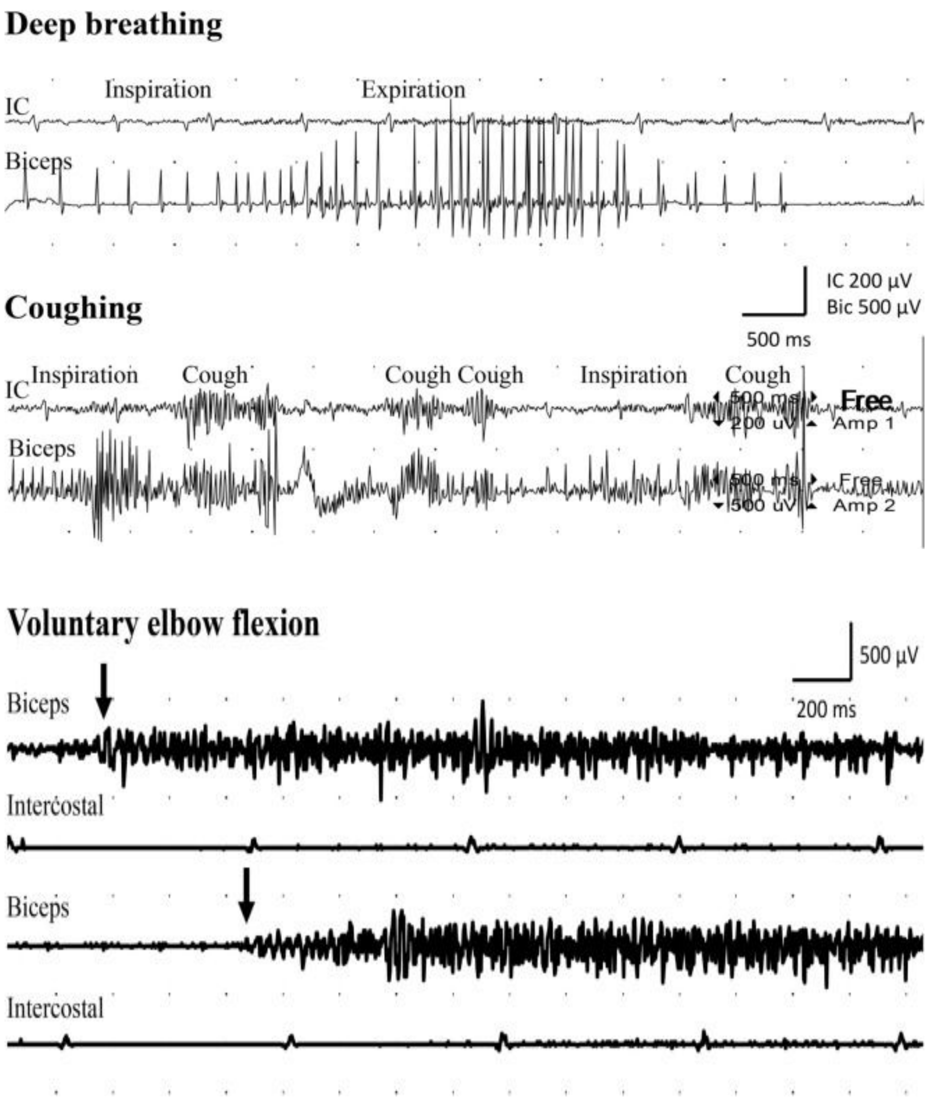
At the dissociation stage the patient would have successfully learnt to voluntary control the recipient muscle. The donor nerve is able to independently contract the recipient muscle.



Bilateral Transfer of Learning

Bilateral Muscle Contractions of Recipient and Donor muscles

Here's an example of association and dissociation phase for the biceps (recipient muscle) and the intercostal muscles (donor muscles). Interference patterns show muscle activity when it contracts and relaxes.



Association phase - Exercise 1

The patient is made to breathe deeply while simultaneously attempting elbow flexion (recipient muscle action). The line graph with the label IC (Intercostal) shows interference whenever the chest muscles inspire and exhale. The line graph below that show the muscle activity of biceps which is at maximum when the chest muscle exhales.

Association phase - Exercise 2

The patient is made to cough along with attempting elbow flexion (recipient muscle action). The Biceps display maximum interference when the patient coughs.

In both the exercises for association the common nerve is acting on the door and recipient muscle. The exercise helps train the nerve to initiate the action at the recipient muscle. This is the association phase.

Dissociation phase

The patient is able to initiate the biceps voluntarily without the triggers from the IC (Intercostal) muscles.

Thus, biofeedback helps the therapist to instruct the patients and communicate the requirements of the exercise though visual feedback. However these readings are primarily for the therapist and the patient may find it difficult to interpret them without some help from the therapist.

3. Ecosystem Study

Over recent years electromyography (EMG) biofeedback devices have become more widely available to physiotherapists. These devices are used for rehabilitation and physical training.

5.1. Biofeedback devices for muscle training
5.2. Muscle Re-education program at Nair & KEM Hospital
5.3. Need for cost-effective EMG biofeedback solution

3.1. Biofeedback Devices for muscle training

The following table presents a comparative study of some popular biofeedback devices and systems in the market.

Category/Products	OT Bioelectrica—Due	Nu-Tek EMG Biofeedback	BioZen products	Shimmer wearable sensor	Enraf-Nonius Myomed 632X	myoMUSCLE™ Software Module	Ultium™ EMG — Sensor module only	flexerGo by Healer Tech
Applications	Sports, ergonomics and rehabilitation.	Pelvic Floor Muscle Assessment and Training with Nu-Tek EMG ETS STIM Devices in clinics and for home use.	To show the user their physical level of relaxation. For clinicians and patients to use biofeedback in and out of the clinic.	High quality, scientifically reliable data to support researchers and academics in their data collection. Thus providing a proof of concept tool to those looking to develop commercial sensing applications.	patient to exercise safely, which efficiently promotes recovery	An all-in-one analysis, enabling detailed insight for performance enhancement, injury recovery or research metrics.	Flexibility to accurately capture the most interesting aspects of human movement. The system features new, patent-pending set of "SmartLeads", which transform the EMG device into an intelligent sensor for virtually any type of biometric and physiological data, from any type of hardware.	It provides clinical grade movement readings for biofeedback, neuromuscular re-education, and strength-power output. Application covers in the following areas: Biofeedback, Therapeutic exercise, Neuromuscular re-education, Pediatrics developmental delay, Postoperative rehabilitation, Sport performance, Injury rehab, Motion tracking, Skills development, Stroke rehab, Spinal Cord Rehab, Traumatic Brain Injury, Pediatrics sensory integration.
Wearable	Yes	**No**	Yes	Yes	**No**	**No**	Yes	Yes
Programmable	No	Yes	No	No	Yes	Yes	No. Yes through PC software	No
Display	No	Yes	No	No	Yes—large	Depends on PC monitor, smartphone	No	No
User UI physical buttons—Physical/Touch	No	Yes/-	No	No	Yes/-	-/Yes	No	No
Number of probes	1	1	No	No	1	-	Versatile Smartleads—Surface EMG, Footswitch (FSR or insole), Fine-Wire EMG, 2D Goniometer, Analog Input Probe (3-channel), Flexiforce Local Pressure Sensor, Physiomonitor (breath/heart rate), Accelerometer, Force Sensor	No

Table 2 : Comparative study of few popular biofeedback devices

Continued table

Number of EMG channels for each probe/Output of the product	2 EMG signals	1 EMG signals	Depends on number of devices used. Body sensors includes electroencephalogram (EEG), electromyography (EMG), galvanic skin response (GSR), electrocardiogram (ECG or EKG), respiratory rate, and skin temperature sensor. Each sensor sends a separate signal to the phone so users can see how their body is responding to their behavior. It displays Delta, Theta, Alpha, Beta, and Gamma brain waves. It can also combine the brain waves to show meditative and attentive cognitive states.	Depends on number of devices used. ECG, EMG*, Respiration, 9 DoF inertial sensing, GSR, PPG, Load, Weight, Force, Torque, Pressure, Integration and prototyping of 3rd party sensors. *EMG and ECG cannot be measured simultaneously on a single unit.	Shows muscle contractions of the patient. An acoustic signal is also possible that indicates whether or not the patient achieves the selected values. The rough EMG-signal is audible via headphones.	EMG signals—signal processing, frequency-fatigue analysis, spectrum analysis, wavelet toolbox, biofeedback analysis.	1 EMG, 1 Integrated IMU sensor which outputs accelaration and gyroscope values	1 EMG signal. App has multiple display modes—envelope curve, gamified display, bar grapgh, comparison—of Real-Time EMG. It also has the ability to analyze and track exercise performance with synchronized video recordings.
Communication	Bluetooth, wired	wired	Bluetooth-coupled sensors	Bluetooth, wired—dock	Bluetooth, wired	Bluetooth, wired	RF	Bluetooth
Apps	PC and smartphones	PC and smartphones	Smartphones	App development in PC for PC and smartphones	PC—through a programmed USB-stick	PC and smartphones	PC and smartphones	Ssmartphones
Internal memory	No	Yes	Hardware—No. Mobile app—Yes	No	Yes	-	internal 8 hours of data logging. (Receiver 2GB onboard memory, up to 18 hours)	No
Working hours	13 hrs	?	?	?	?	-	?	?
Battery charging mode	wireless	wired	wired	wired—dock	wired	-	wired—dock	wired
Battery type	Li-Po battery	?	?	?	?	-	?	?
Price	?	£264.00 / $329.31	Depends on number of devices used. Each device cost between $75 and $150	?	?	Free	?	$587.00

Table 2 (contd.) : Comparative study of few popular biofeedback devices

3.2. Muscle Re-education program at Nair & KEM Hospital

Hospitals like KEM and Nair, offer free rehabilitation to patients who come there for physiotherapy after having undergone nerve transfer surgery. Patients take a minimum of 1 year to show considerable recovery. They are expected to meet the therapist at least once a week. Adherence to rehabilitation is crucial to recovery but it requires great motivation. The therapists play an important role in keeping the patient committed to the rehabilitation. Apart from physical rehabilitation, they counsel the patients and provide them with an understanding of their condition. Counselling is important as the patients may suffer from depression which only reduces the capacity of the brain to function with its maximum potential. Amongst the other challenges that these patients face is the distance they must travel for a half-an-hour session. Some patients decide to live at a nearby location for a period of 2-3 months to receive rehabilitation regularly. Renting a place to stay near the centre also adds to the cost of the treatment that the patients must bear. If the patient desires to go back home for a break, the therapists fear a halt in progress as the patient may not exercise enough (could be as much as 400 repetitions a day). It is also important that the patient practices the exercises with the correct method than just try to complete the prescribed number of repetitions.

Image 15: The Image on the left shows a young patient (13 yrs) who suffered a BPI after being hit by a truck. She underwent surgery in February 2019 and has been receiving rehabilitation at KEM hospital since then. From left to right: Dr Bharti Thosar, the patient, Dr Chhaya V, Prathamesh and Miti (interns)

Myomed 134 is one of the biofeedback devices in supply that are imported. The device was purchased three years ago, by the Physiotherapy Dept at Nair hospital. Despite the usefulness of the device, it laid barely used by the physiotherapists due to various reasons. On interacting with the therapists, it was found that the device had some technical issues in the first year of usage but due to a change in the administration which happened at around the same time of purchase, nobody had taken solid initiative to get it fixed. And it laid unused for quite some time. In a more recent attempt to fix the device, the suppliers were unable to repair the device and it was sent back to the hospital in the same state. We can say that difficulty in use and maintenance of the device were primary cause for the failure of such technology in the therapy centre. A lack of ownership was evident too which could also be due to its lack of usage and poorly perceived value.

“We are trying to use it... But still we are struggling with it...”

“Currently I have got too many patients so I’m not getting the time to use it. Cause I had kept it for charging one day.”

Image 16: Physiotherapists at Nair Hospital being explained how Myomed 134 works.

3.3. Need for cost-effective EMG biofeedback solution

Lack of frequent use and maintenance affects the device. The value of the money spent for the product as well as the product is lost. Most of these devices are complex in nature and can be used mostly by professionals. If not used regularly the components lose its ability to function accurately. Due to infrequent use the device gets affected and won't function as it's supposed to.

Most of such devices are complex in nature. It could be because these manufacturers make these products with an intention to use the device for many applications so they come feature rich. But for doctors as well as for hospitals, not all the features might come of use. However they have to pay for the whole product and all its features.

Popular consumer products in the market have -

1. Very straightforward application, handy and easy maintenance.
2. Their components in the product is available in the market too which makes it easy for repair.
3. Ease of distribution and purchasing
4. Low cost device that is affordable for the patient to use too.

In India where speciality hospitals are very few, distance to receive treatment is high and so the cost to travel increases overall burden on an average patient.
Since rehabilitation requires monitoring and frequent assessment of the therapist, opportunity to reduce cost lie in creating mobile phone based products for self-monitoring and providing patient education.

4. Problem statement

To develop an easy to use product that provides biofeedback for muscle re-education exercises in Brachial Plexus Rehabilitation. Both the therapist and the patients should be able to use it with ease.

5. Scope

Purpose

1. The product will assist a Brachial Plexus injury patient in muscle re-education during physical rehabilitation.
2. The product will achieve this by capturing muscular biofeedback signals [1] of the injured limb during exercise that will be delivered using a visual display, acoustic or haptic signals.
3. This biofeedback will depict muscle strength when the patient applies voluntary effort.
4. Being aware of the strength applied and how much more must be applied to meet the requirements of the exercise will help the patient to perform repetitions effectively.
5. Reactive visuals that are intuitive, recreational and appealing will help the patient to be responsive and stay motivated.
6. A smartphone is proposed as a medium for displaying biofeedback to make the solution portable.
7. The application will be assistive and instructional in nature.
8. The assistive app will feature details of exercises and help the patient follow the routine independently.

Themes: mobile, assistive, neuromuscular biofeedback, brachial plexus injury, injury rehabilitation

User group

1. Patients who have succeeded to establish an association between donor and recipient muscles. They can carry out a joint action using the recipient muscle while co-contracting.
2. These patients are not dependent on electrical stimulation for recruiting recipient muscle. Their recipient muscles are at MRC1/5.

4. Further strengthening will require more repetitive exercise where visual biofeedback can strengthen the newly formed neural pathways in the brain.
5. Only for android
6. The app can connect to only two sensor units at its current stage.

Functional objectives

1. Product is lightweight portable wireless and wearable.
2. Surface electrodes that are easy to put on by the patient.
3. Two channels that receive EMG signals - one pair for the donor muscle and other pair for the receiver muscle.
4. Neuromuscular biofeedback is displayed on the phone.
5. The app instructs the patient on the placement of sensor units and it contains exercises specific to the patient's condition.
6. The app also has daily exercise goals set for the patient.
7. The report can be shared to the therapist.

Usability goals

Device is easy to set up and use

1. The user is able to set up the device with ease in less time.
2. The user is able to identify and locate the donor and recipient muscle on his/her body.
3. The user is able to attach the electrodes at the correct muscle and correct position.
4. The user can understand when the electrodes are correctly or incorrectly placed.

Device instructs the user through different exercises

5. The user will be able to follow the steps for exercising.
6. The user is able to understand how interactive visuals and sounds are reacting to his/her muscular functions.
7. The user is able to understand if s/he isn't doing the exercises correctly.

Device allows the user to have an exercise routine and follow it.

8. The user is able to meet daily exercise goals.

6. User Scenarios and Product concepts

The design of the product included designing the user experience of a consumer biofeedback product.

Empathy Maps
We first studied the patient-therapist interactions at a physiotherapy centre using empathy maps. These empathy maps were created out of insights that were derived while observing patient-therapist communication at Physiotherapy departments of KEM and Nair hospital.

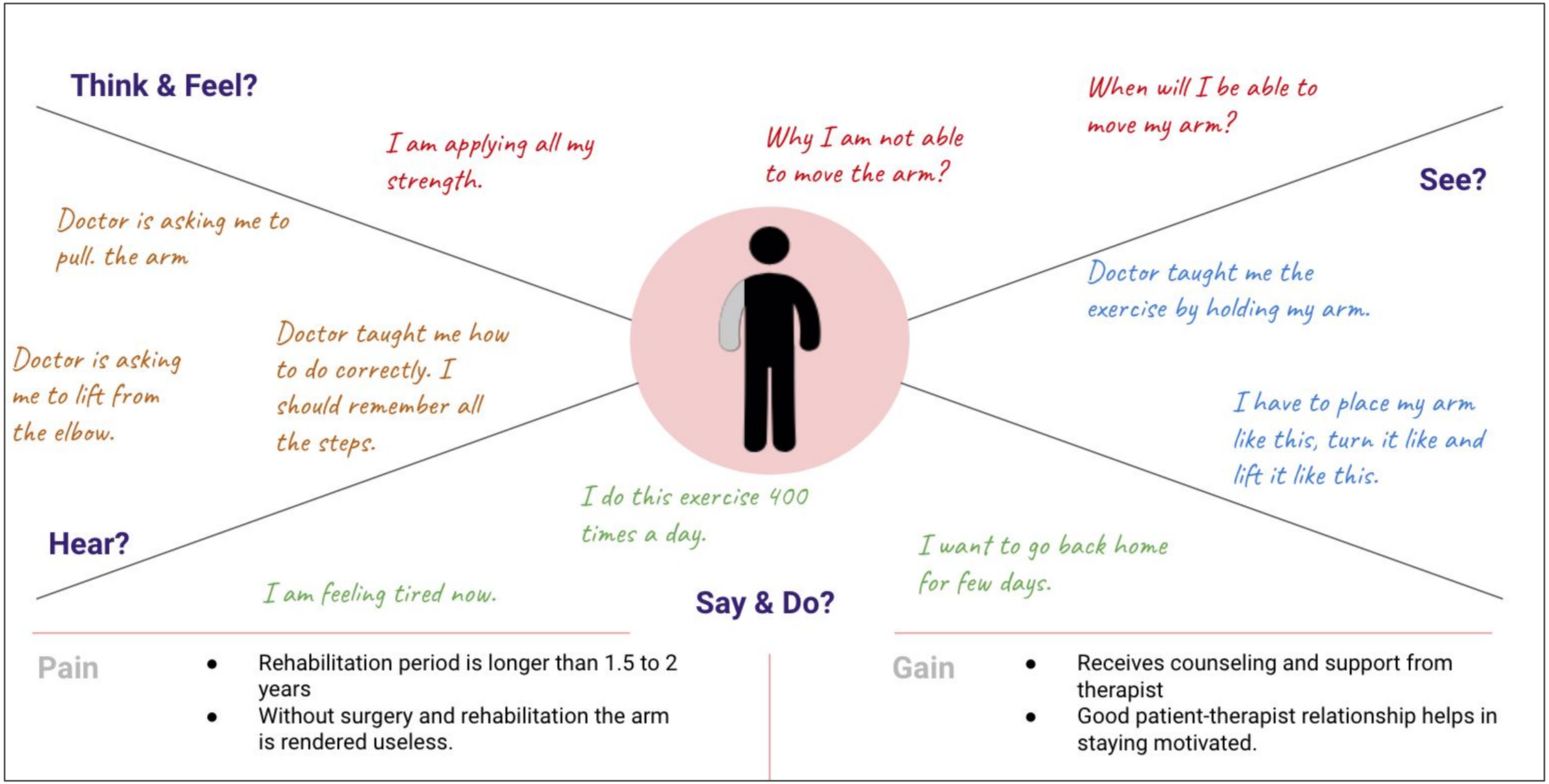


Image 17: Empathy Map of a BPI patient

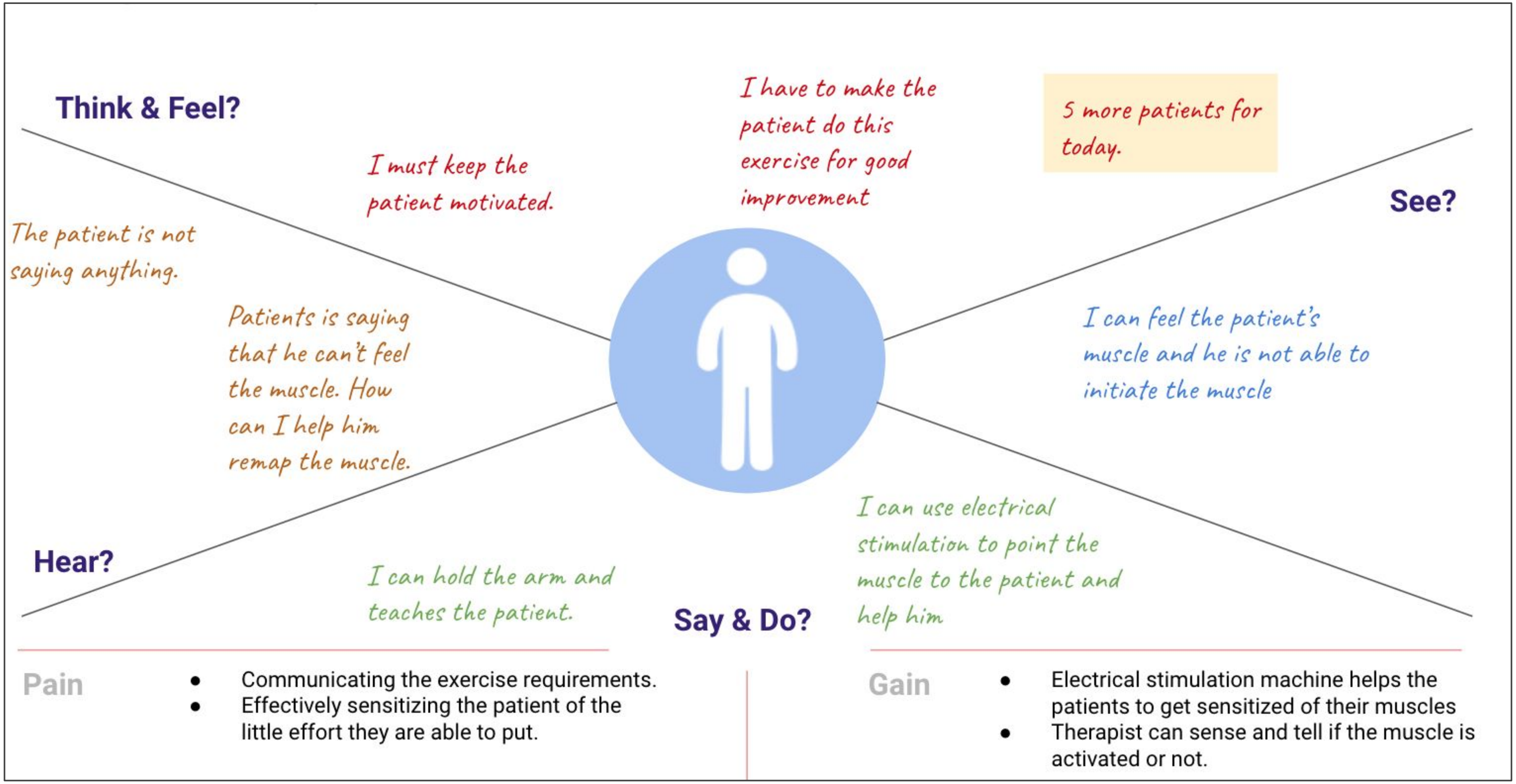


Image 18: Empathy Map of a Physiotherapist

Product concept 1

Simple device that has two channels for two sets of electrodes and it send the data to mobile phone app via Bluetooth or OTG.

cons

- wired
- not so easy way to put electrodes. ppl can get confused with cathode and anode placements

pros

- display is replaced by the mobile app
- verified the quality of the sensor and if the signals are received on the phone well.

Product concept 2

In order to ease the electrode placement step, we found another off-the-shelf sensor which comes with anode and cathode fixed at a standard distance.

We also explored on making a stand-alone unit by adding an OLED.screen.

Product Concept 3

We added bluetooth to continue sending the data to the app. The OLED can show real time biofeedback while the app is used for instructional aspects.

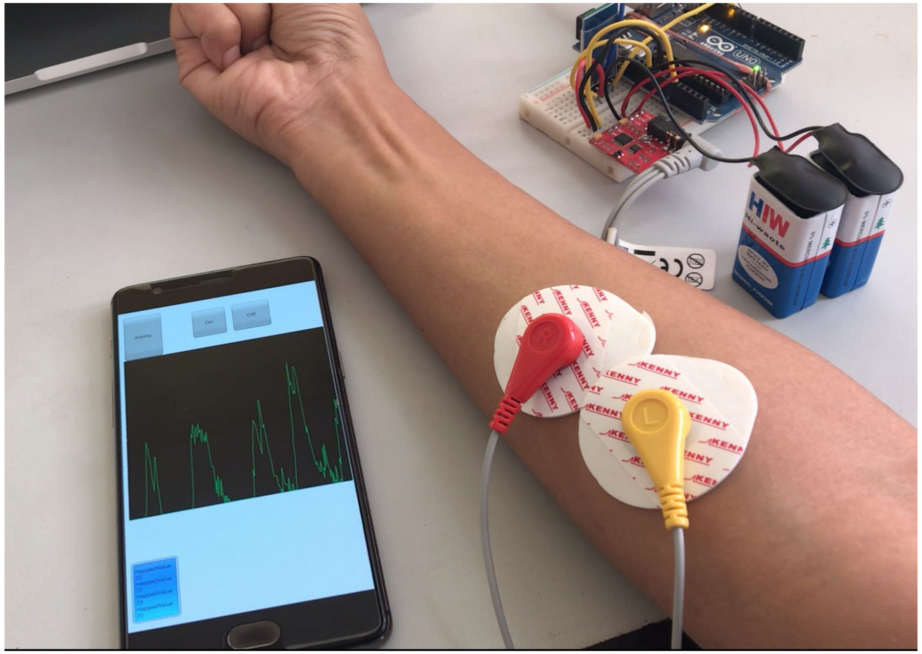
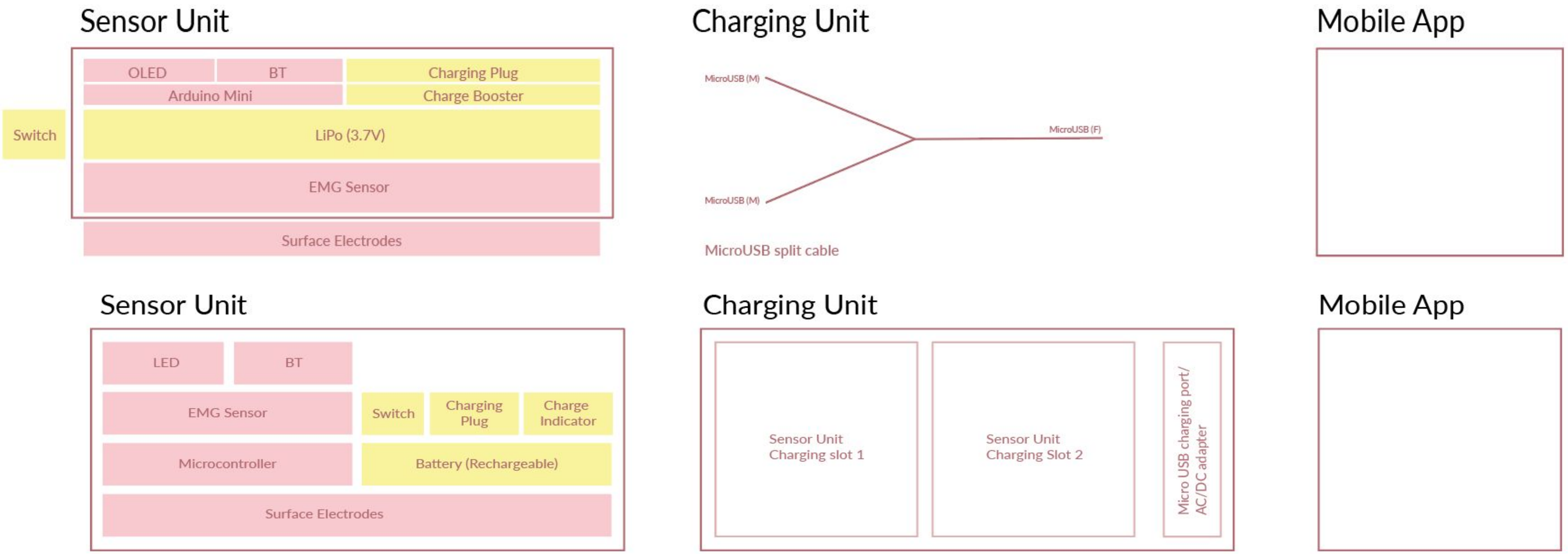


Image 19: Proof of Concept



Charging and sensor unit ideas for product concepts 2 and 3

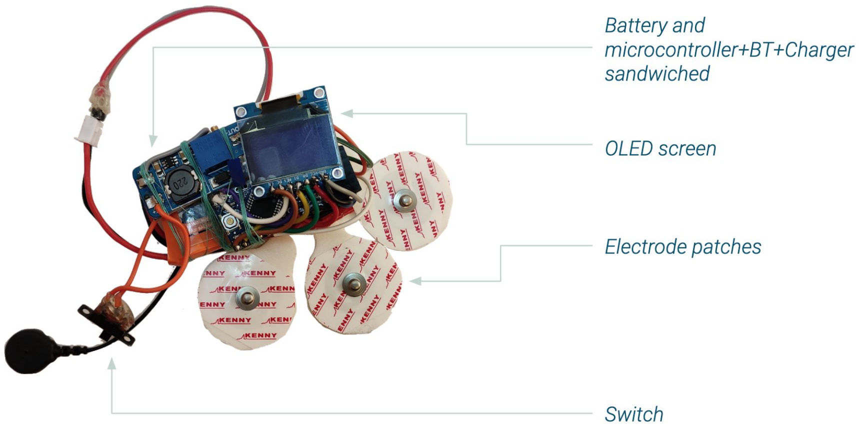
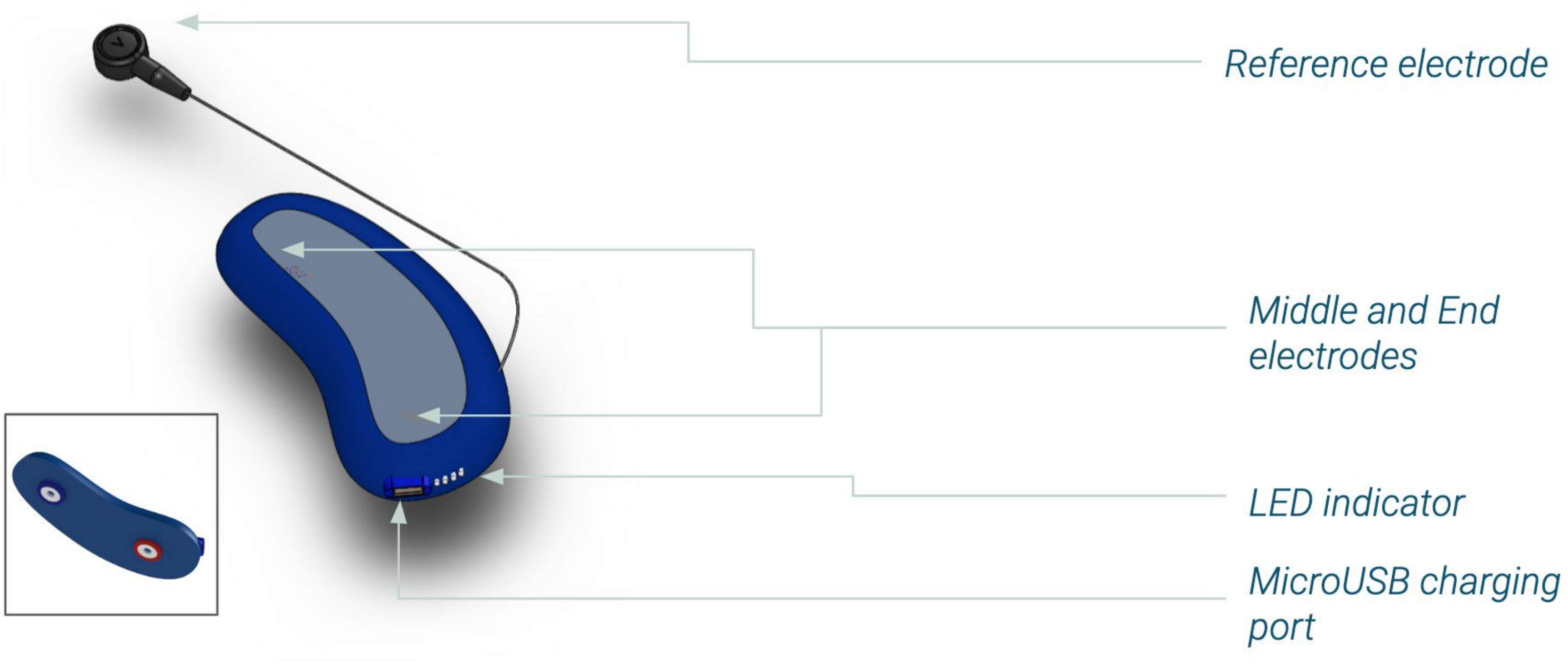


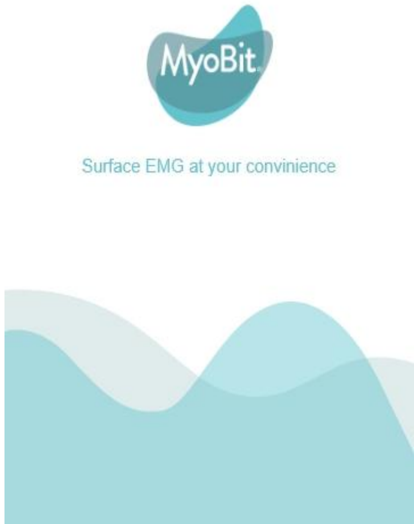
Image 20: Product Prototype V2 with OLED screen

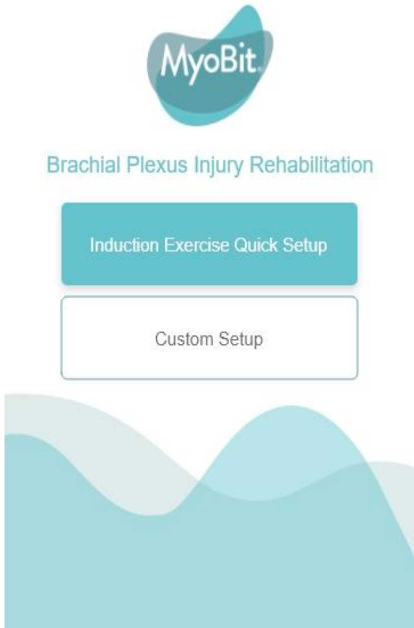
7. Final Product Concept

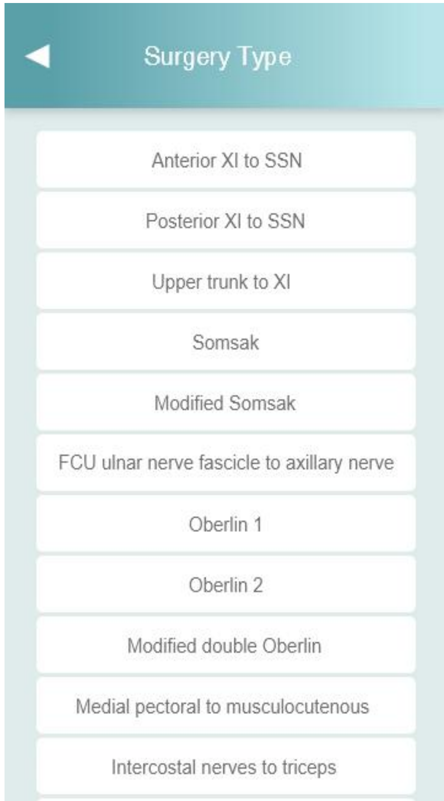


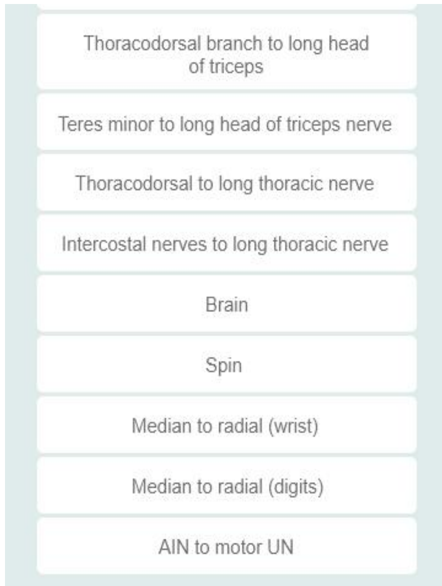
Proposed form for the final product

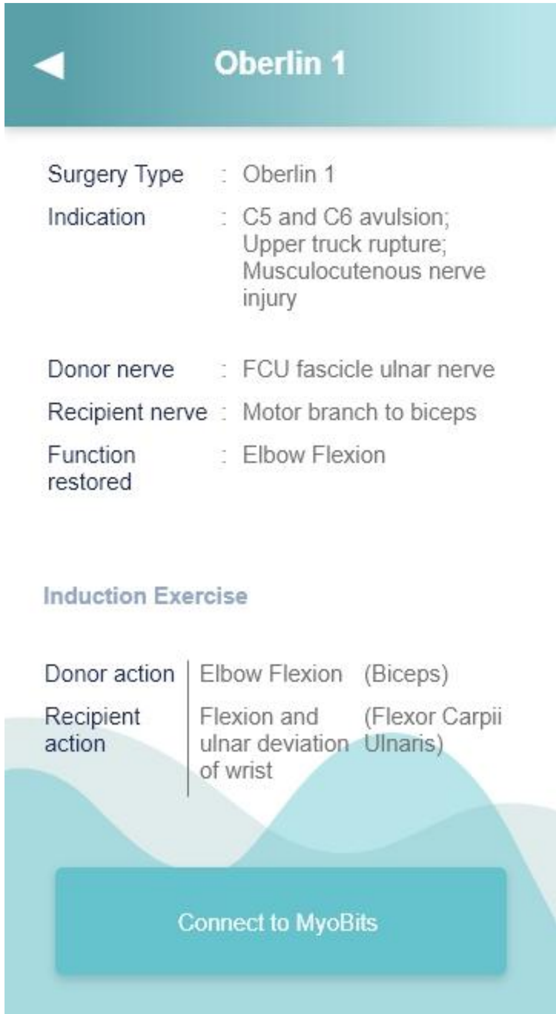
High Fidelity—For Therapist

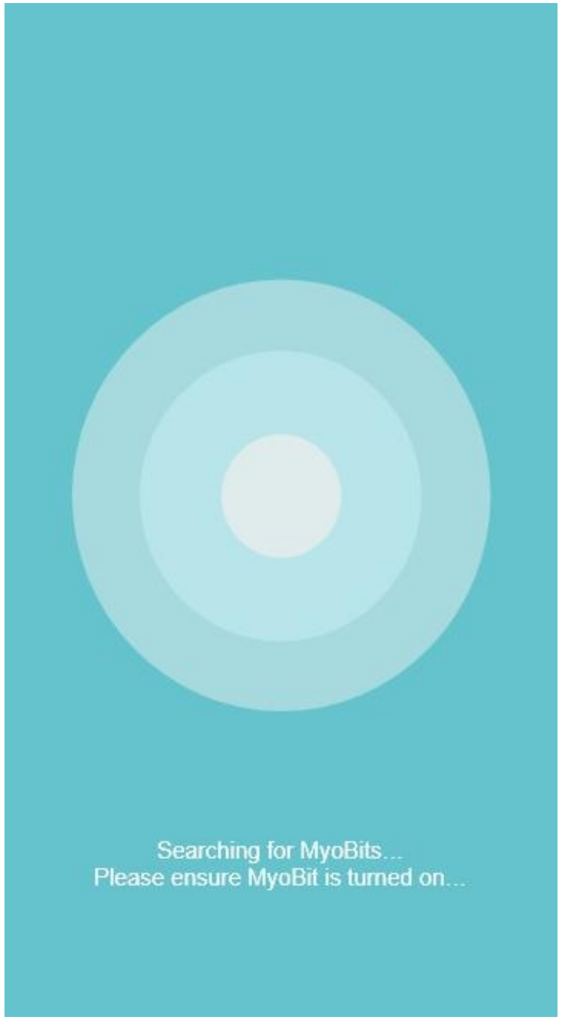


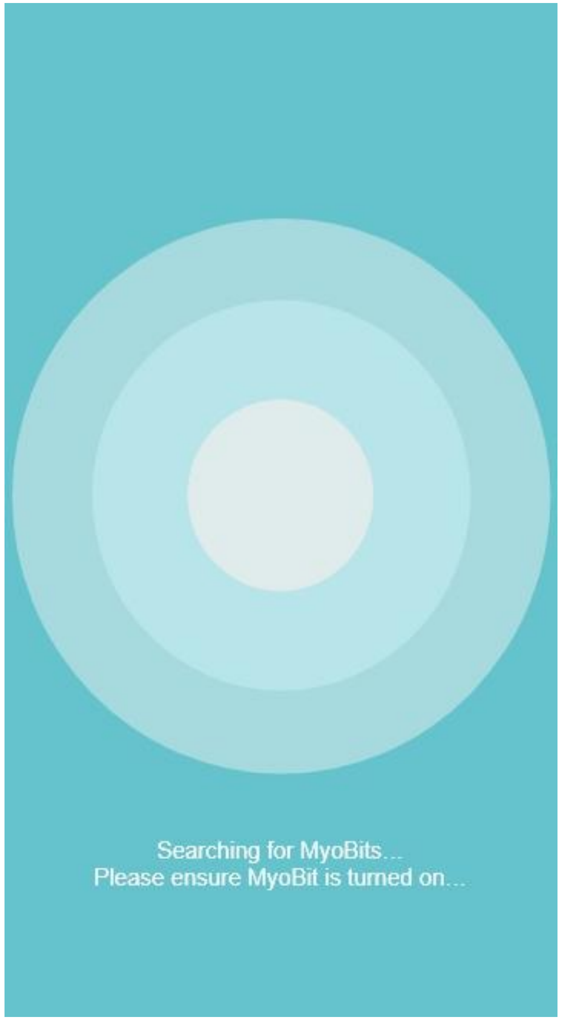


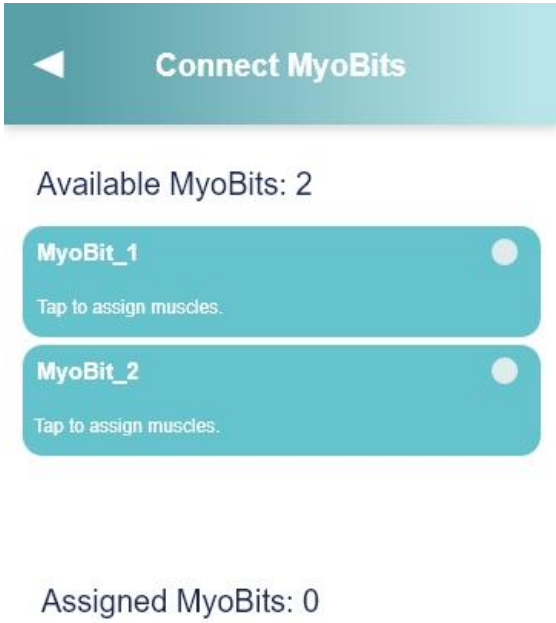


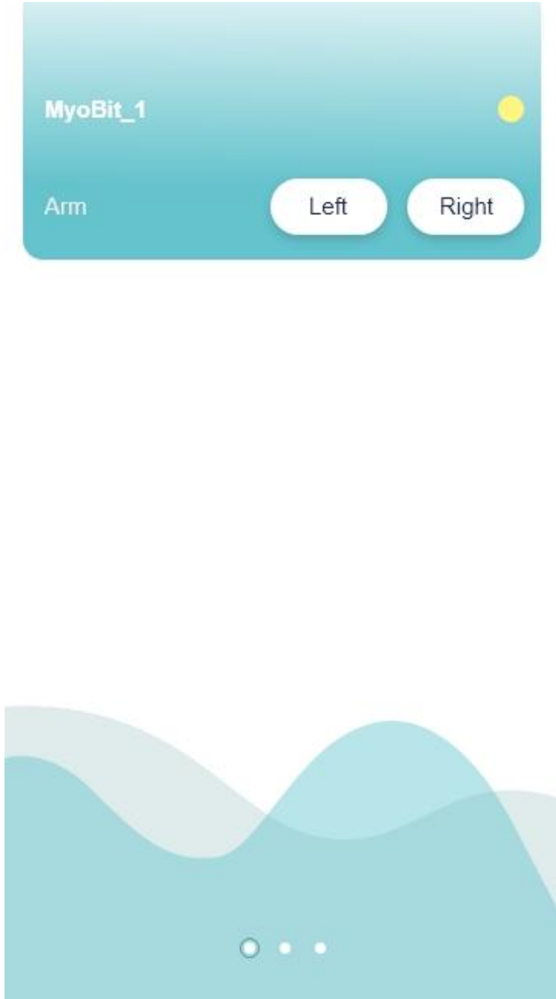



Oberlin 1
Surgery Type : Oberlin 1
Indication : C5 and C6 avulsion; Upper truck rupture; Musculocutenous nerve injury
Donor nerve : FCU fascicle ulnar nerve
Recipient nerve : Motor branch to biceps
Function restored : Elbow Flexion
Induction Exercise
Donor action | Elbow Flexion (Biceps)
Recipient action | Flexion and ulnar deviation of wrist (Flexor Carpii Ulnaris)
Connect to MyoBits

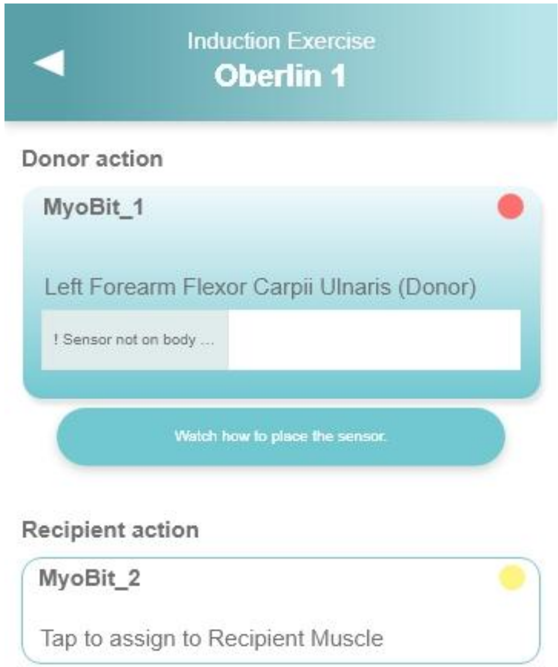

Searching for MyoBits...
Please ensure MyoBit is turned on...

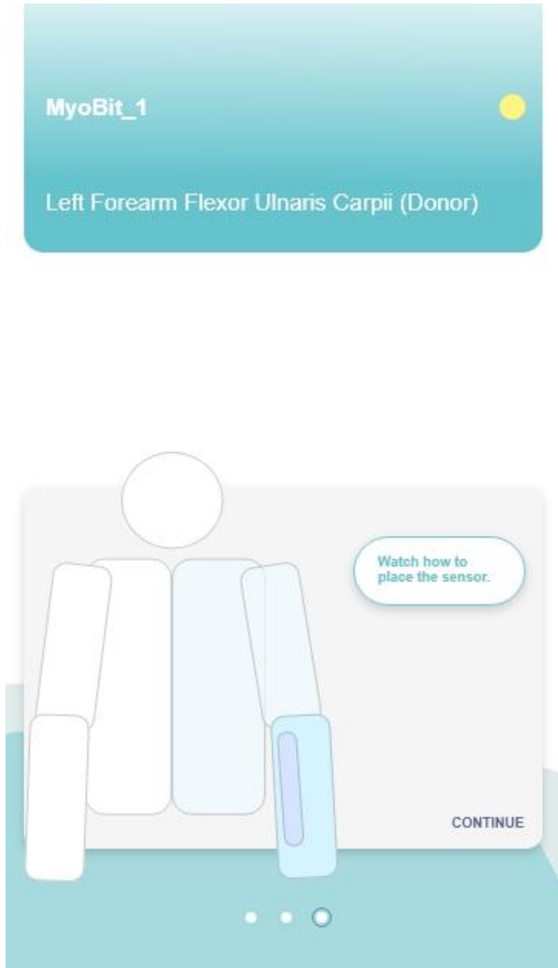

Searching for MyoBits...
Please ensure MyoBit is turned on...

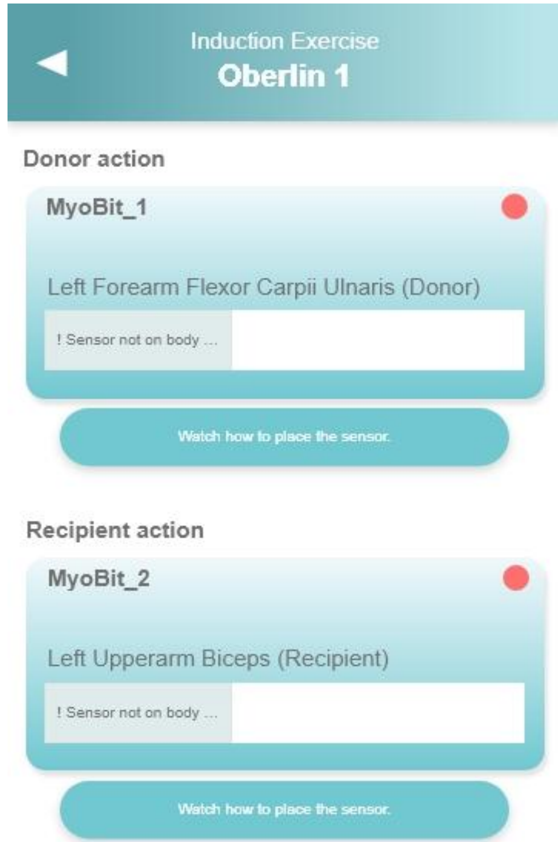

Connect MyoBits
Available MyoBits: 2
MyoBit_1
Tap to assign muscles.
MyoBit_2
Tap to assign muscles.
Assigned MyoBits: 0

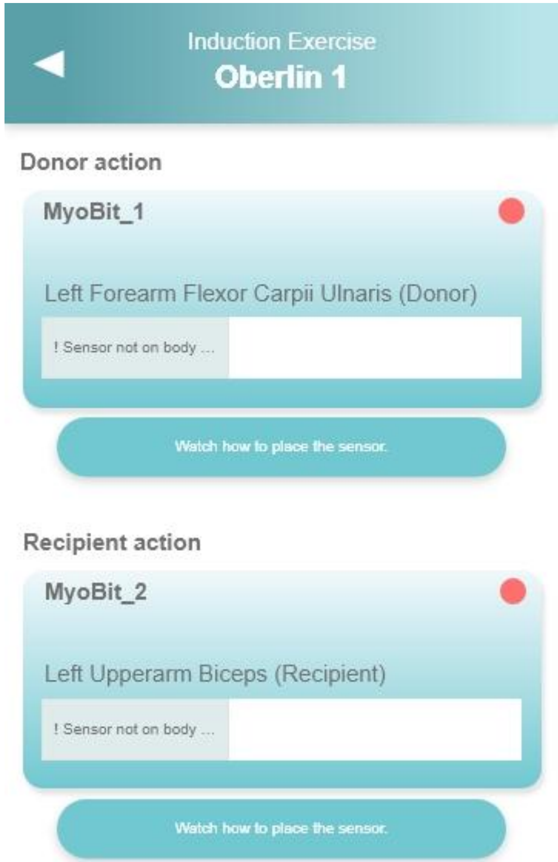

MyoBit_1
Arm
Left
Right

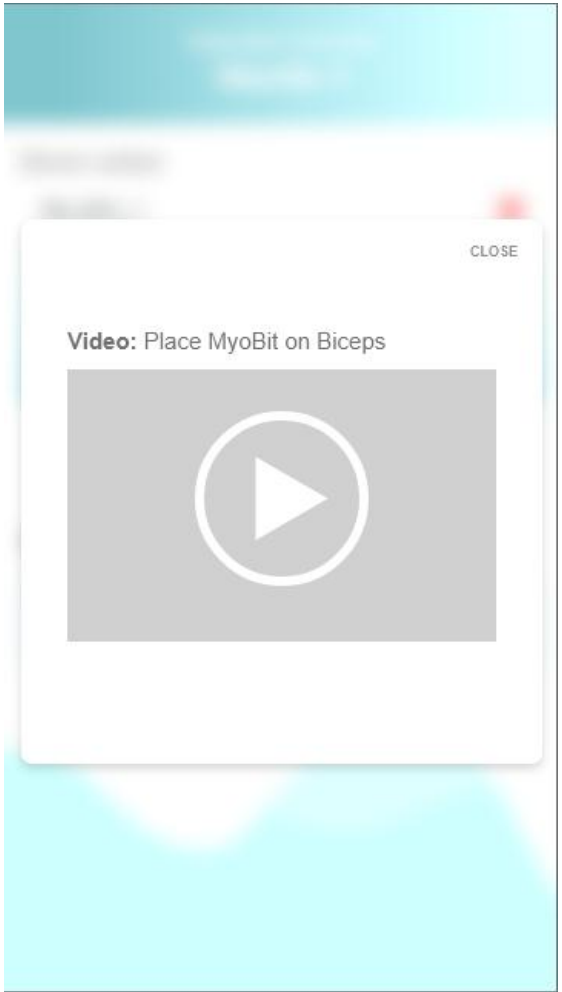

MyoBit_1
Left Arm
Assign to:
Donor action
Elbow Flexion
(Biceps)
Recipient action
Flexion and ulnar
deviation of wrist
(Flexor Carpii Ulnaris)

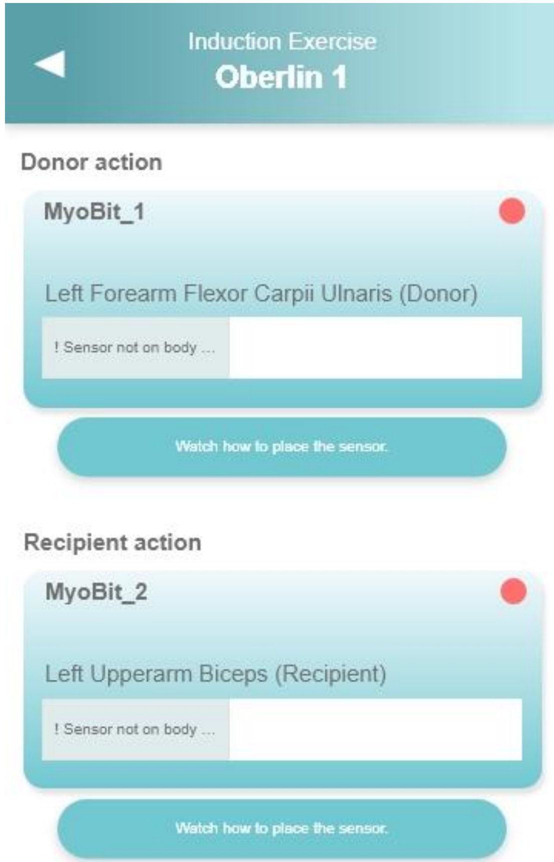

Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
! Sensor not on body ...
Watch how to place the sensor.
Recipient action
MyoBit_2
Tap to assign to Recipient Muscle

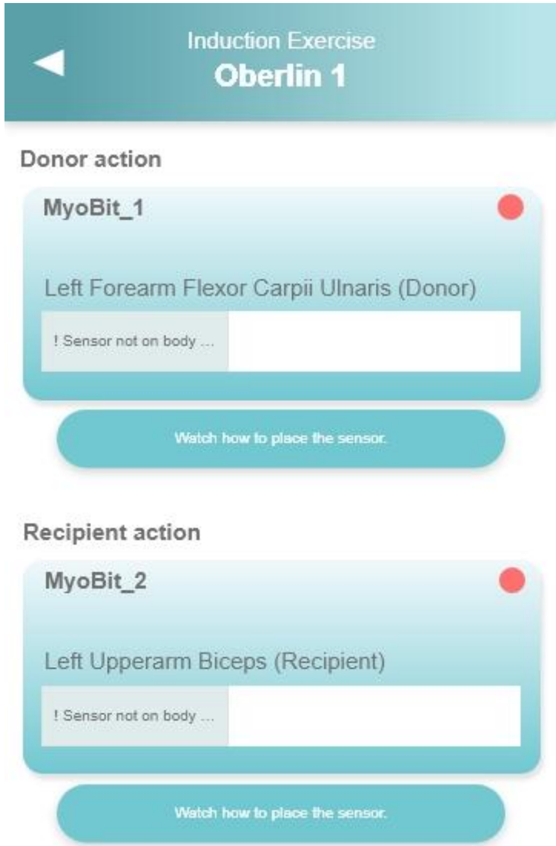

MyoBit_1
Left Forearm Flexor Ulnaris Carpii (Donor)
Watch how to place the sensor.
CONTINUE


Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
! Sensor not on body ...
Watch how to place the sensor.
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)
! Sensor not on body ...
Watch how to place the sensor.


Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
! Sensor not on body ...
Watch how to place the sensor.
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)
! Sensor not on body ...
Watch how to place the sensor.

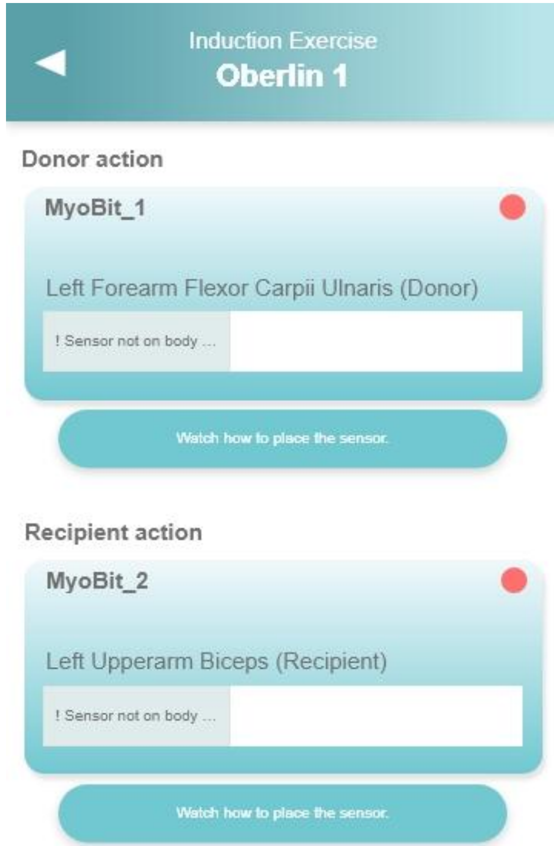

CLOSE
Video: Place MyoBit on Biceps


Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
! Sensor not on body ...
Watch how to place the sensor.
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)
! Sensor not on body ...
Watch how to place the sensor.

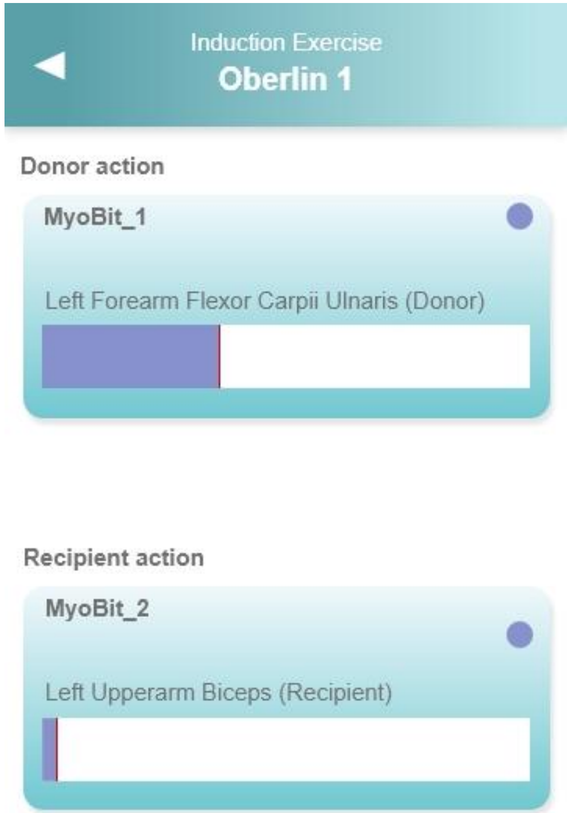


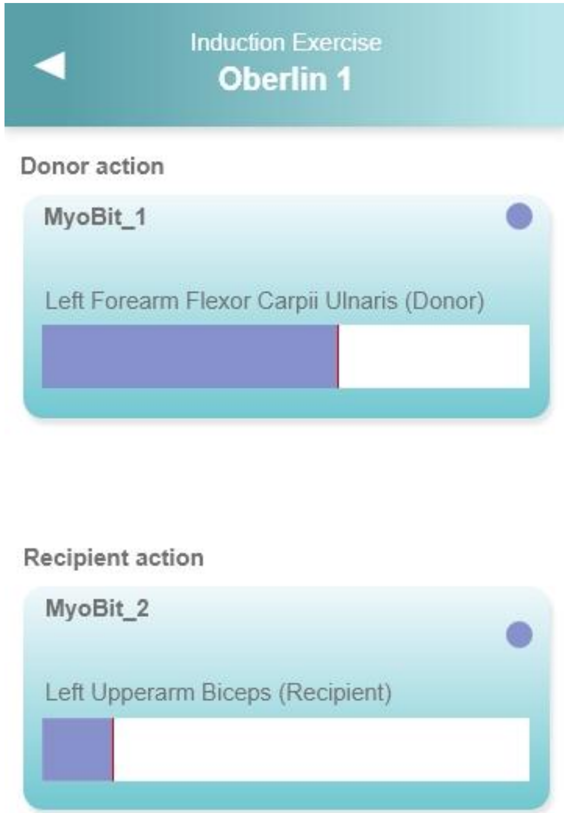
Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
! Sensor not on body ...
Watch how to place the sensor.
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)
! Sensor not on body ...
Watch how to place the sensor.

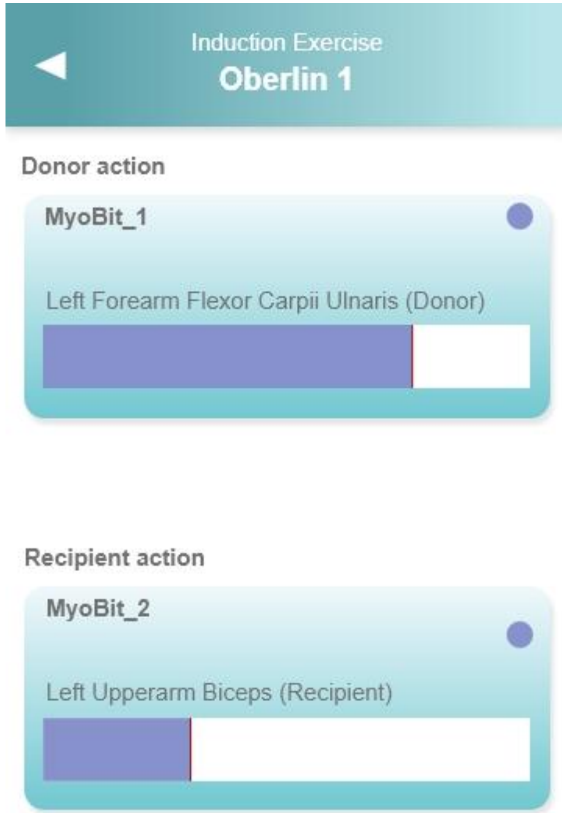
CLOSE
Video: Place MyoBit on FCU

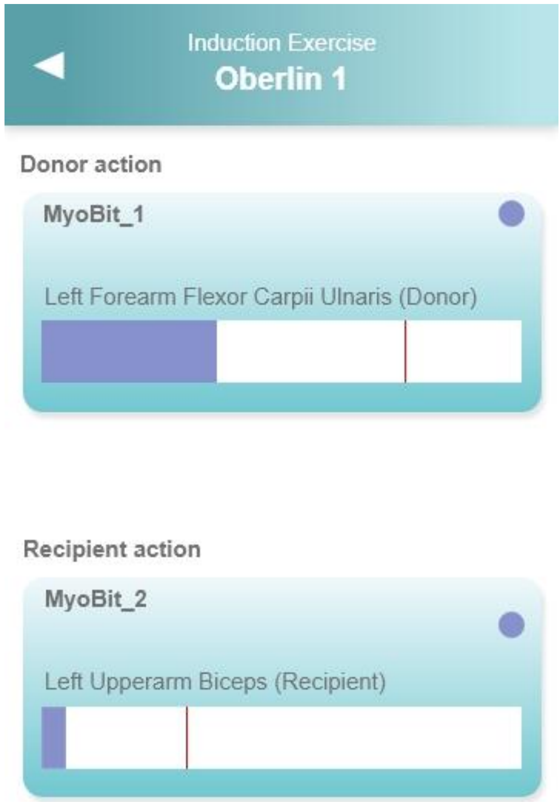


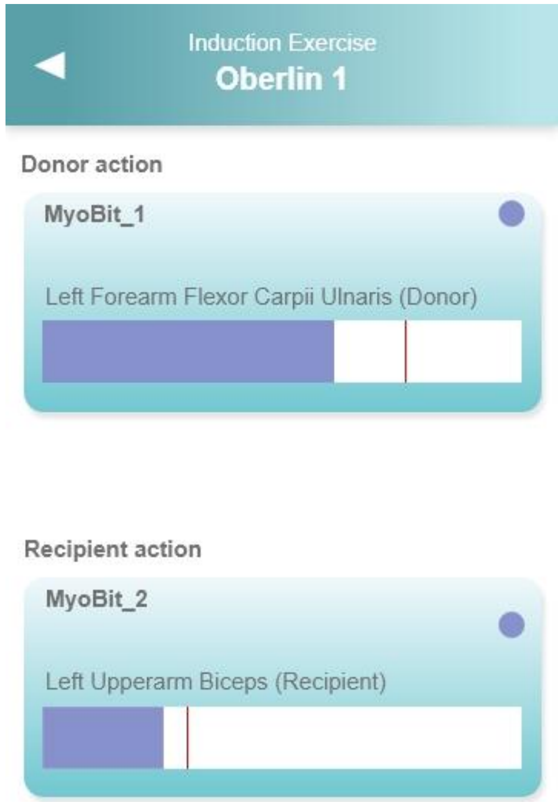
Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
! Sensor not on body ...
Watch how to place the sensor.
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)
! Sensor not on body ...
Watch how to place the sensor.

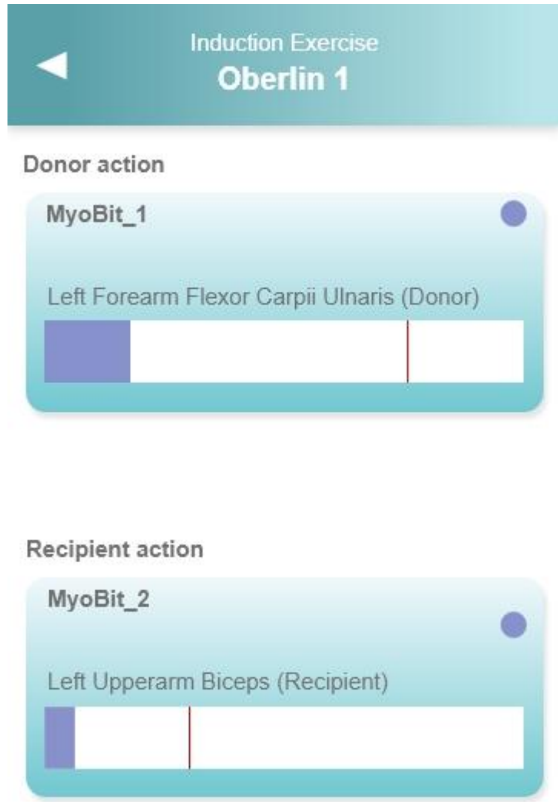

Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)


Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)

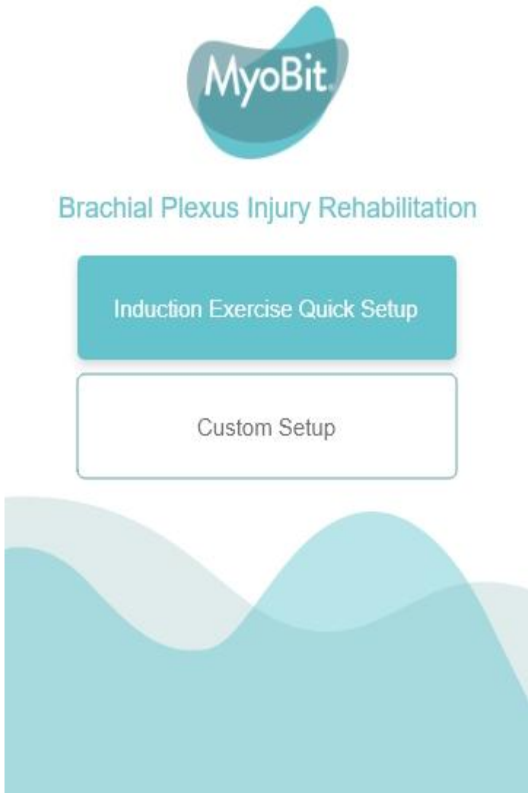

Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)

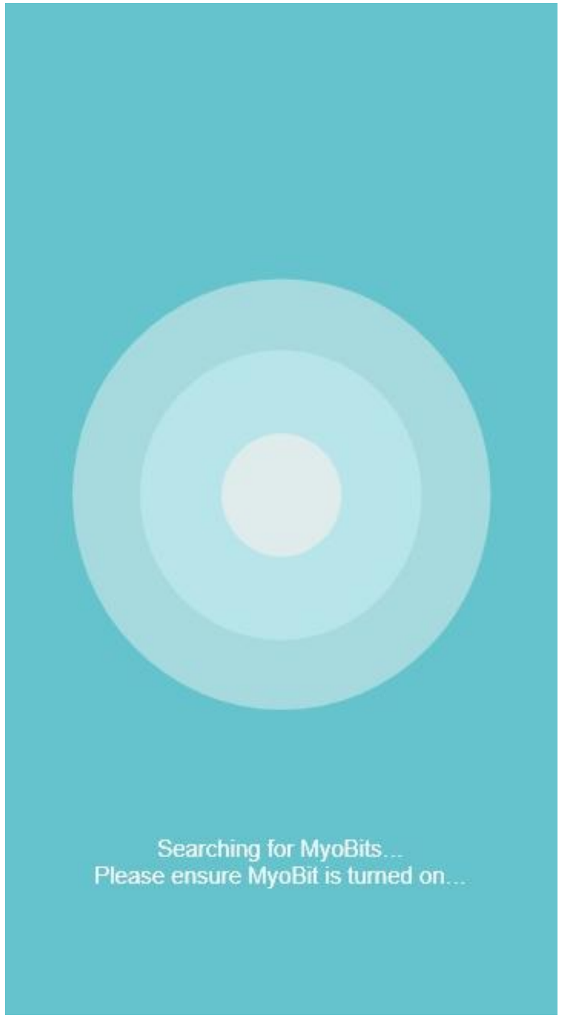

Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)

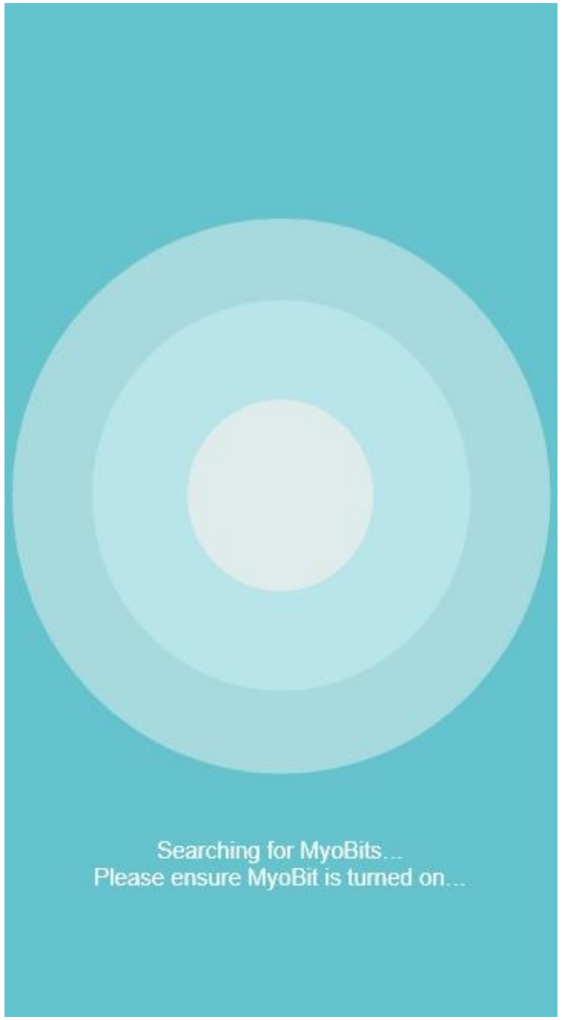

Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)

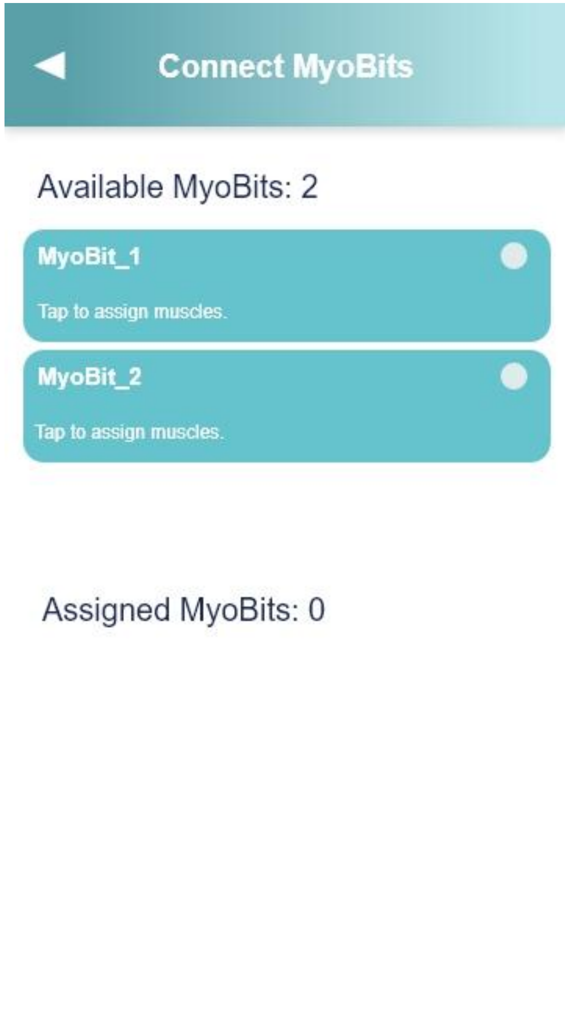

Induction Exercise
Oberlin 1
Donor action
MyoBit_1
Left Forearm Flexor Carpii Ulnaris (Donor)
Recipient action
MyoBit_2
Left Upperarm Biceps (Recipient)

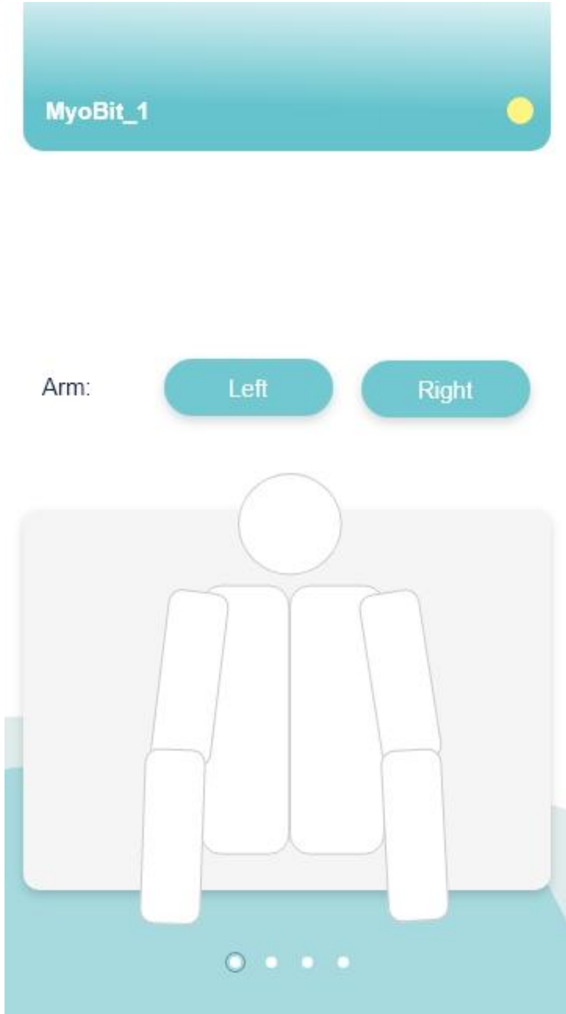
High Fidelity—For Patient

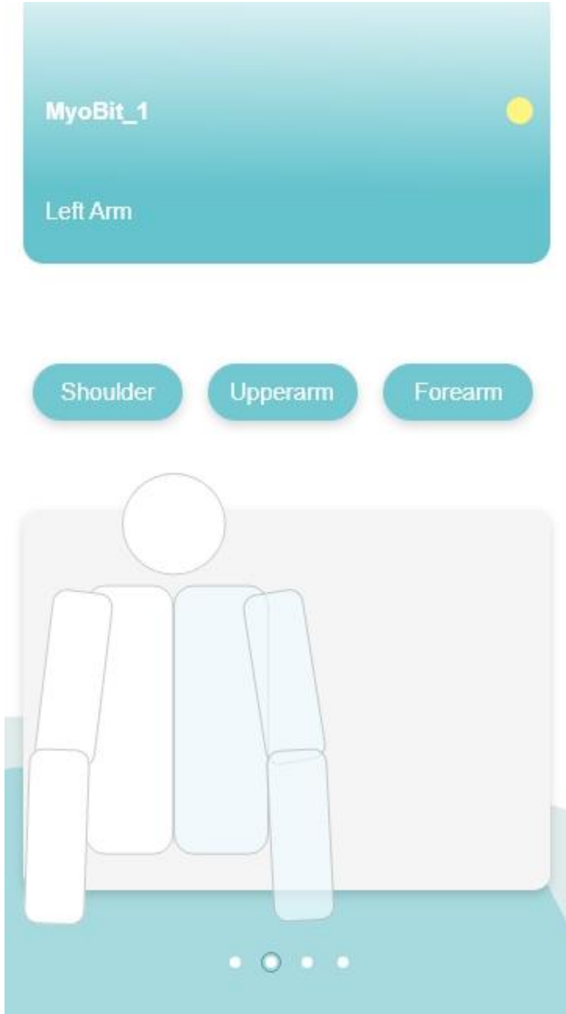


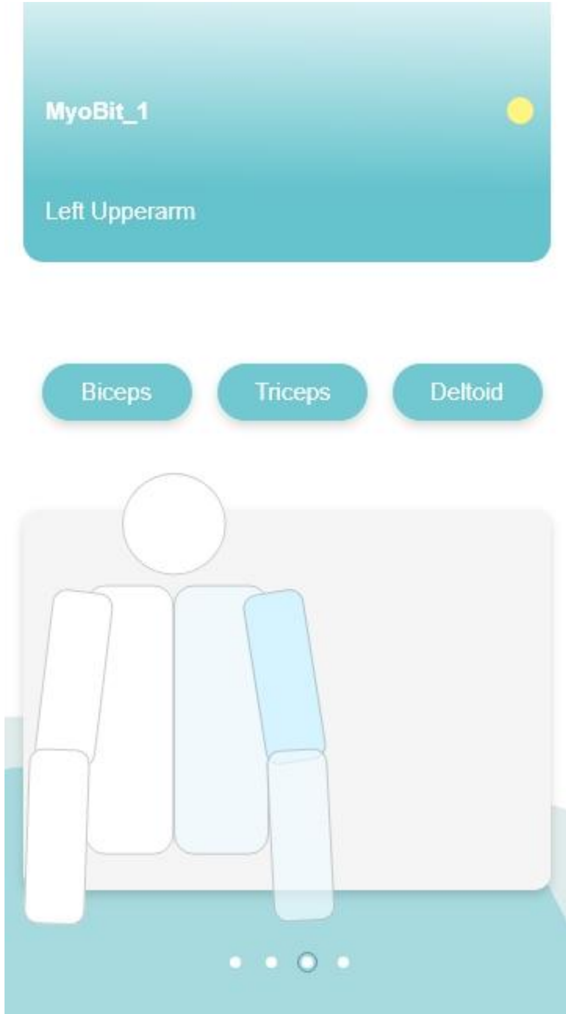


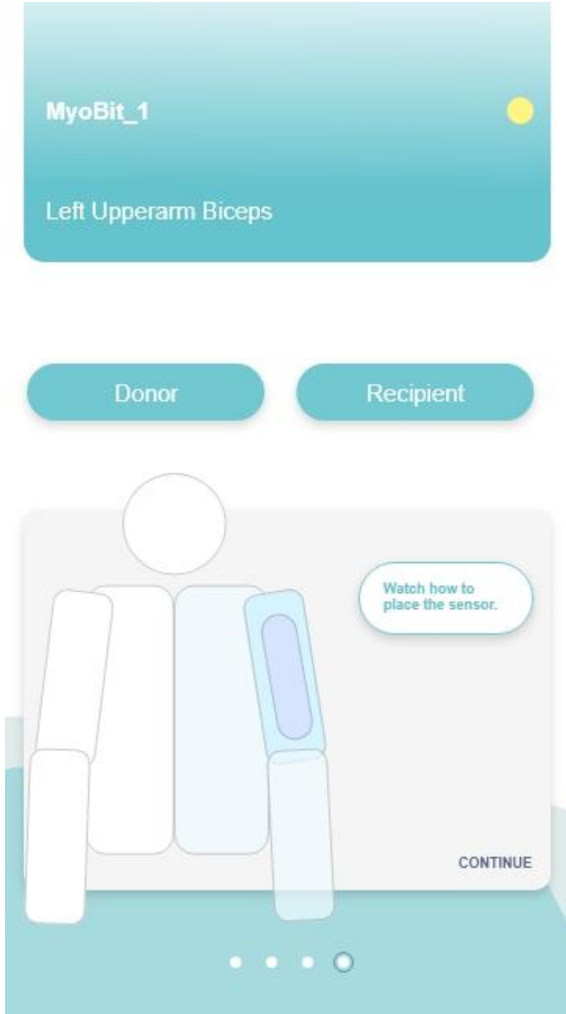

Searching for MyoBits...
Please ensure MyoBit is turned on...

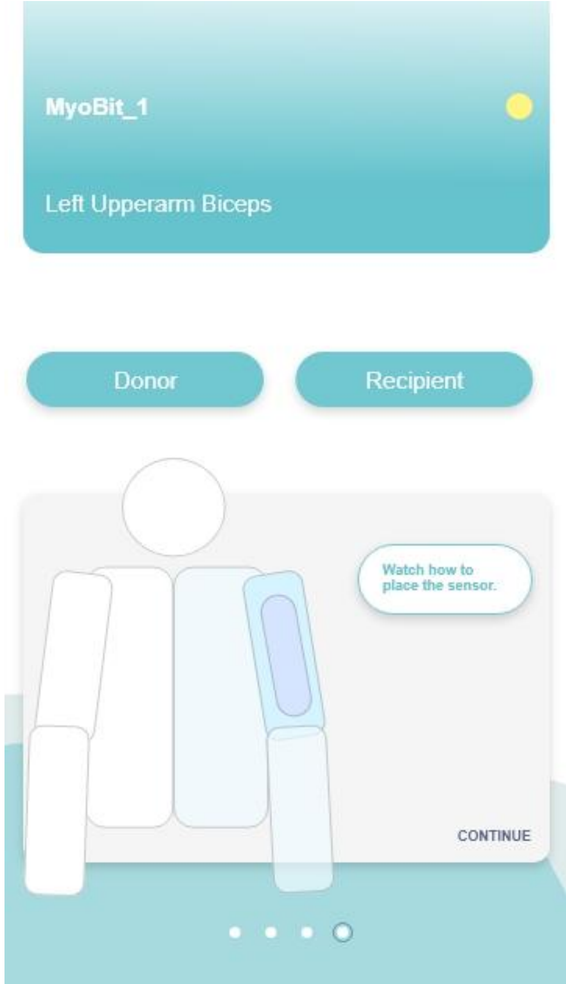

Connect MyoBits
Available MyoBits: 2
MyoBit_1
Tap to assign muscles.
MyoBit_2
Tap to assign muscles.
Assigned MyoBits: 0

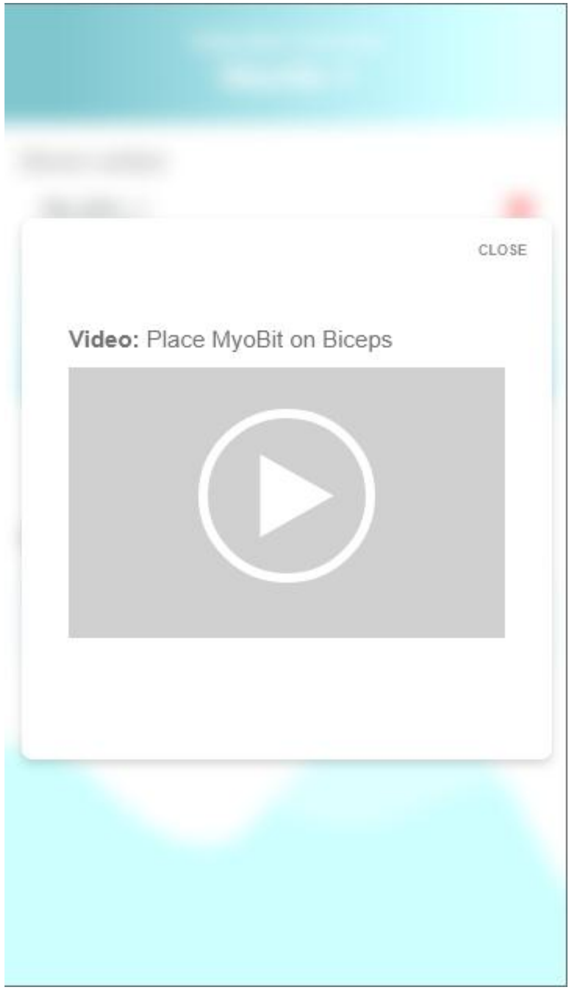

MyoBit_1
Arm:
Left
Right

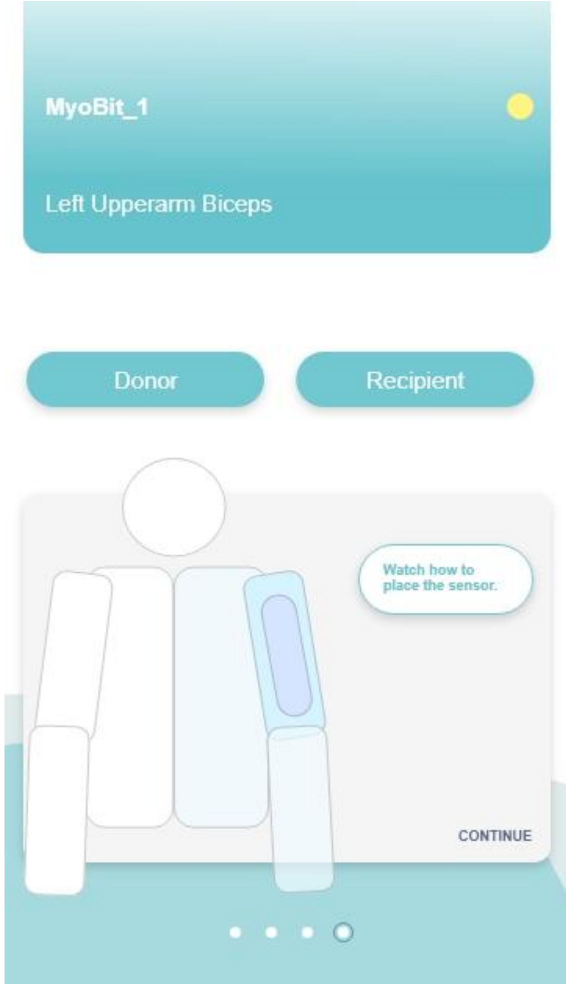

MyoBit_1
Left Arm
Shoulder
Upperarm
Forearm

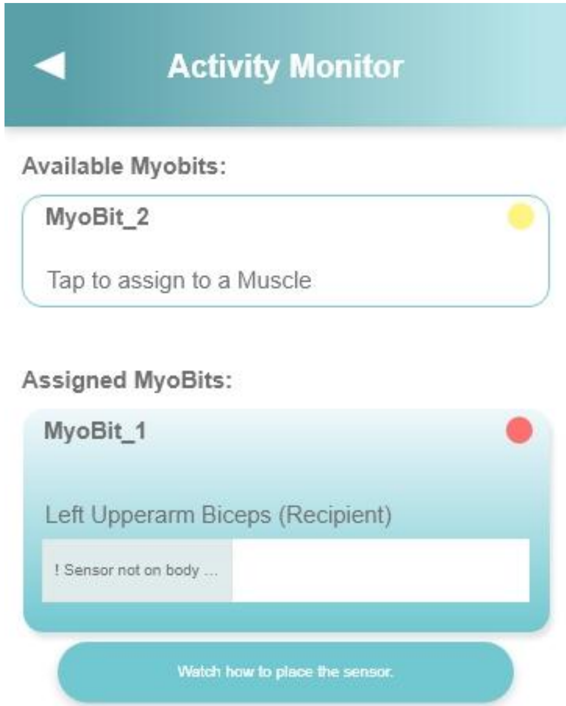

MyoBit_1
Left Upperarm
Biceps
Triceps
Deltoid

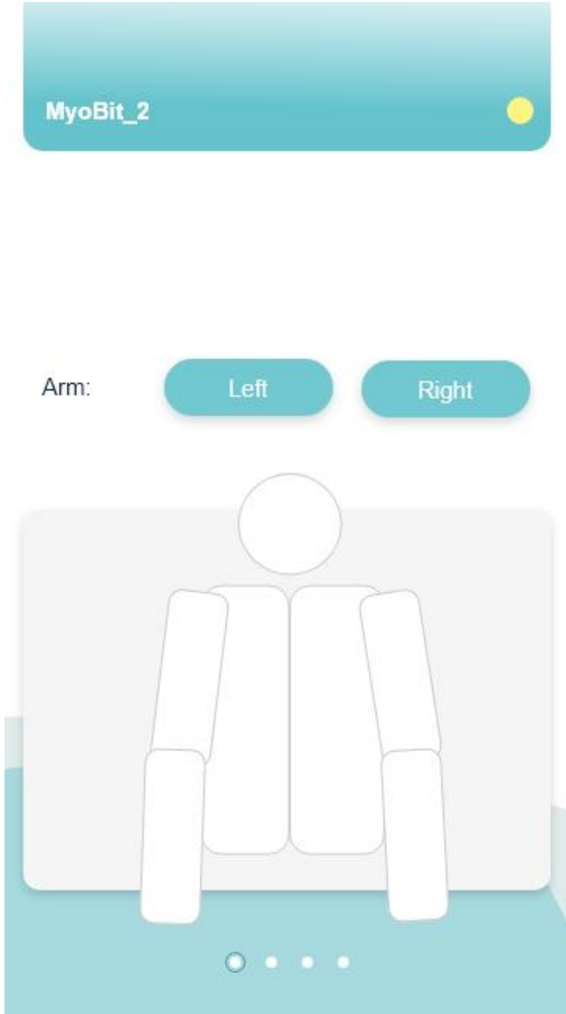

MyoBit_1
Left Upperarm Biceps
Donor
Recipient
Watch how to place the sensor.
CONTINUE

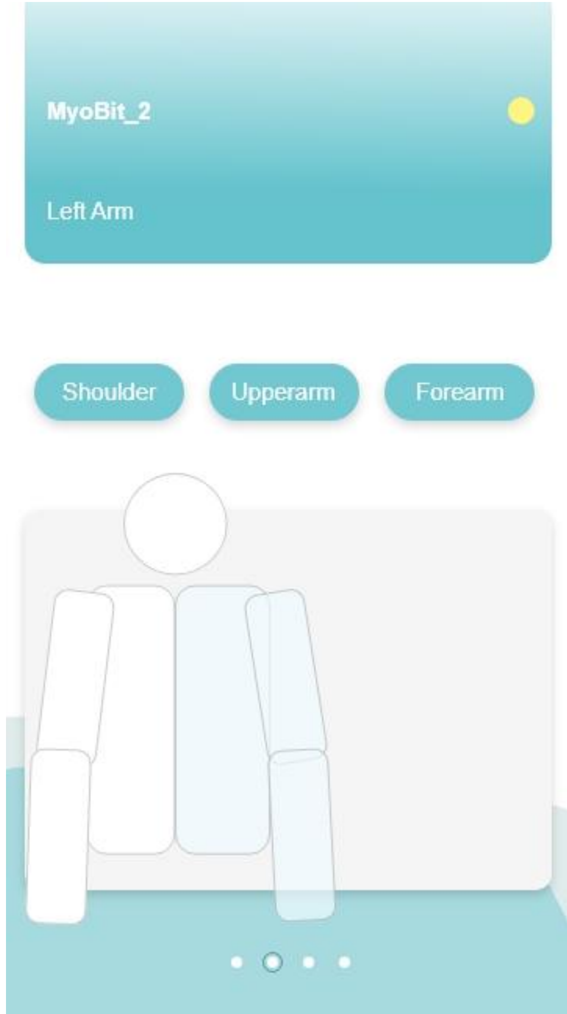

MyoBit_1
Left Upperarm Biceps
Donor
Recipient
Watch how to place the sensor.
CONTINUE

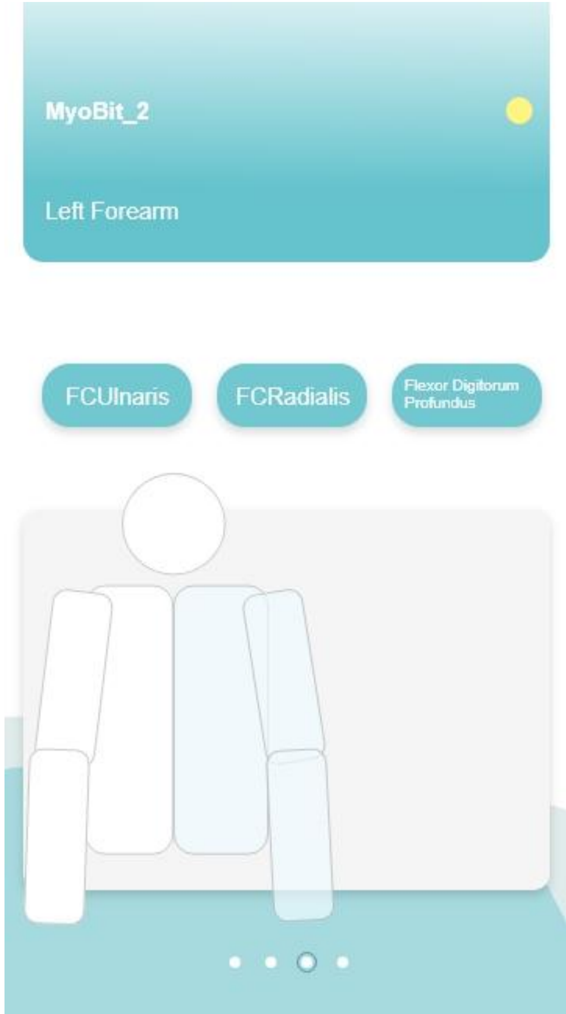

CLOSE
Video: Place MyoBit on Biceps

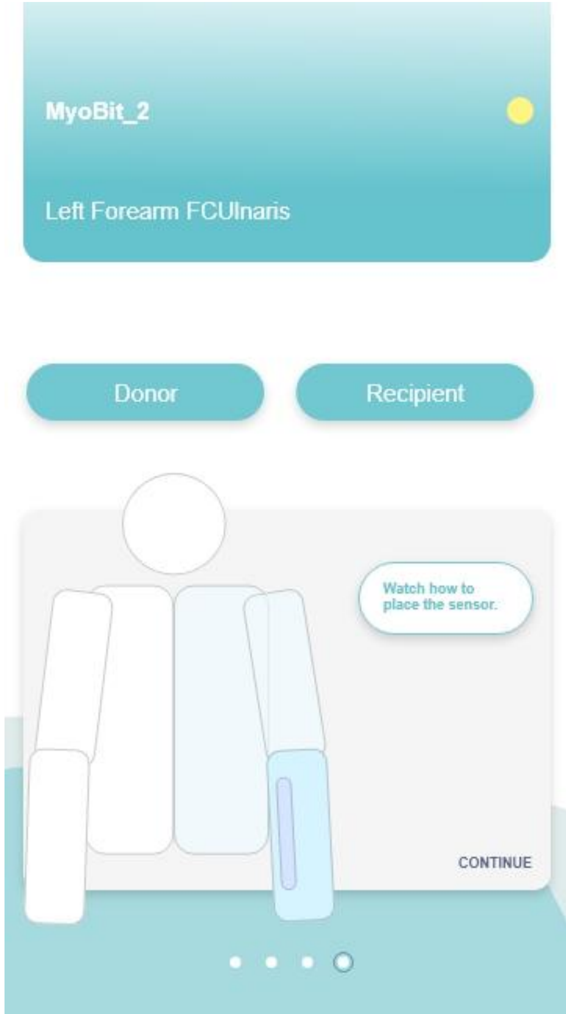

MyoBit_1
Left Upperarm Biceps
Donor
Recipient
Watch how to place the sensor.
CONTINUE

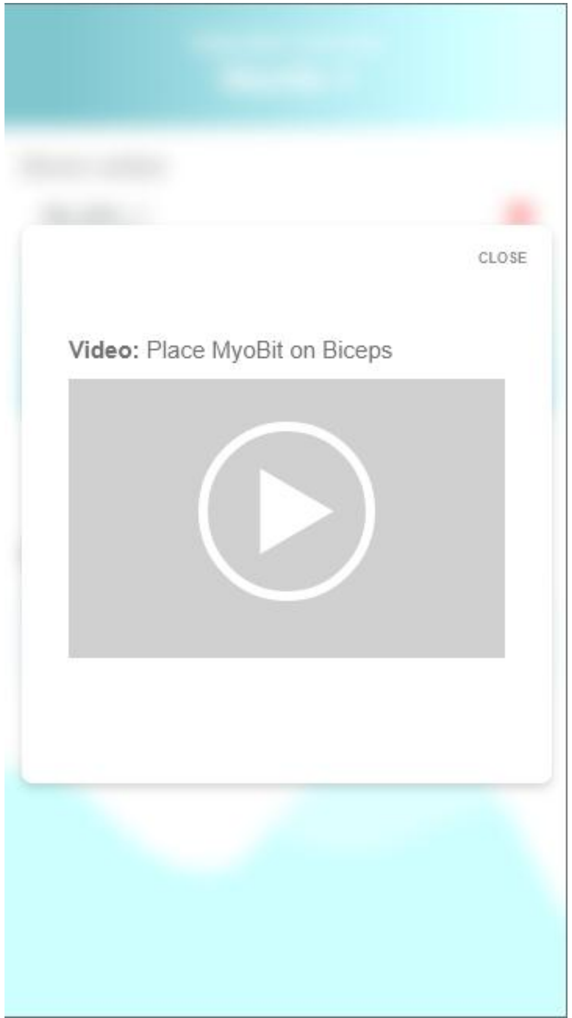

Activity Monitor
Available Myobits:
MyoBit_2
Tap to assign to a Muscle
Assigned MyoBits:
MyoBit_1
Left Upperarm Biceps (Recipient)
! Sensor not on body ...
Watch how to place the sensor.

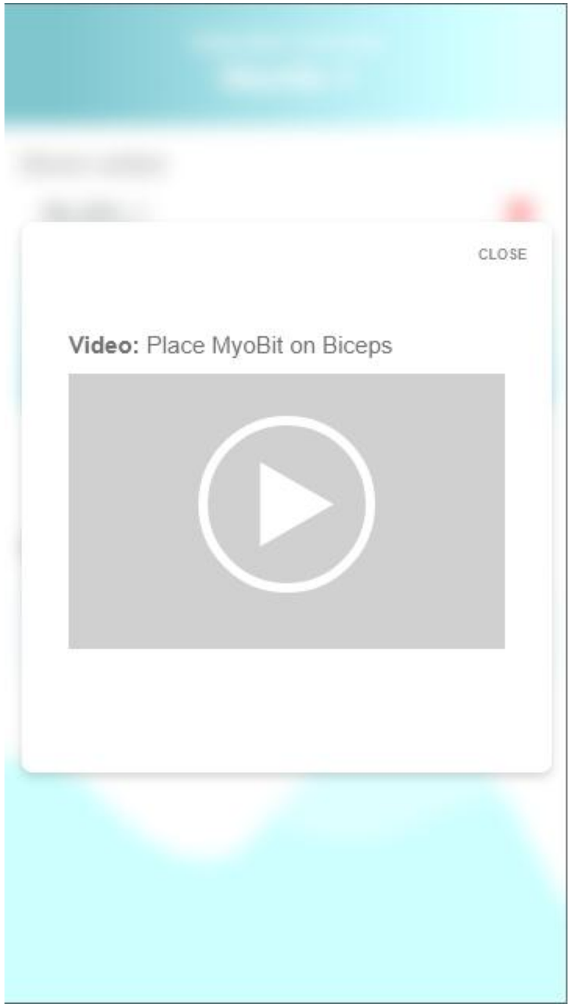

MyoBit_2
Arm:
Left
Right

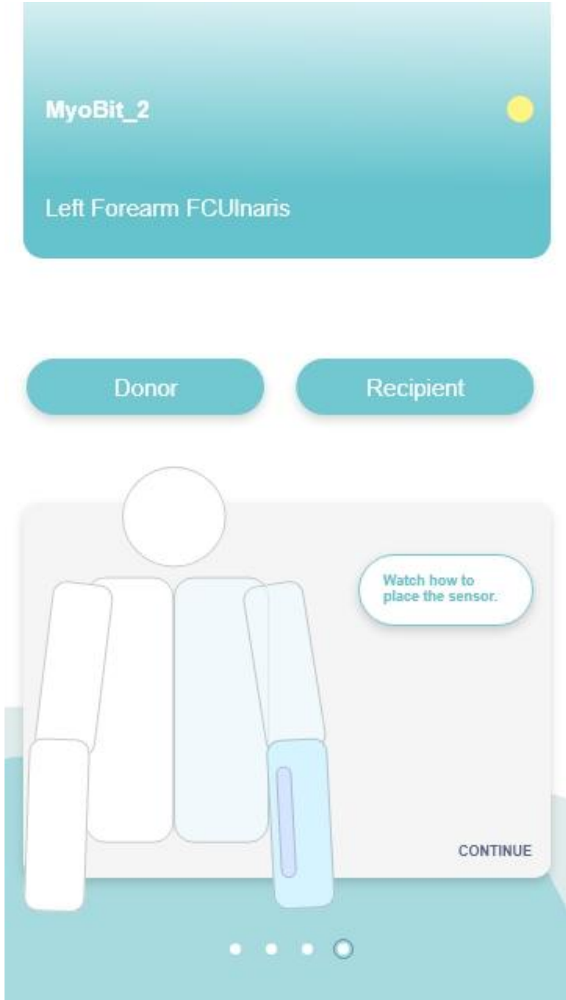

MyoBit_2
Left Arm
Shoulder
Upperarm
Forearm

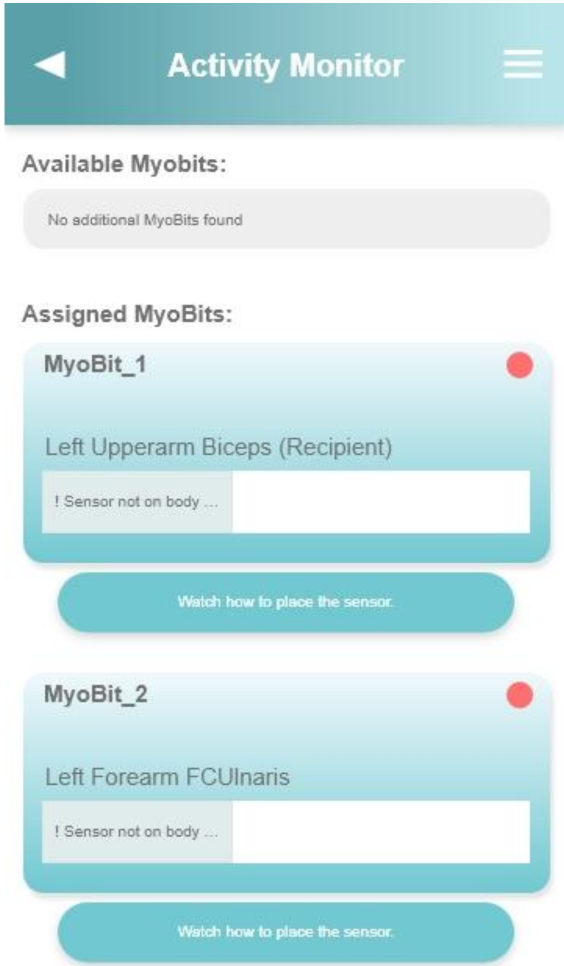

MyoBit_2
Left Forearm
FCUlnaris
FCRadialis
Flexor Digitorum Profundus

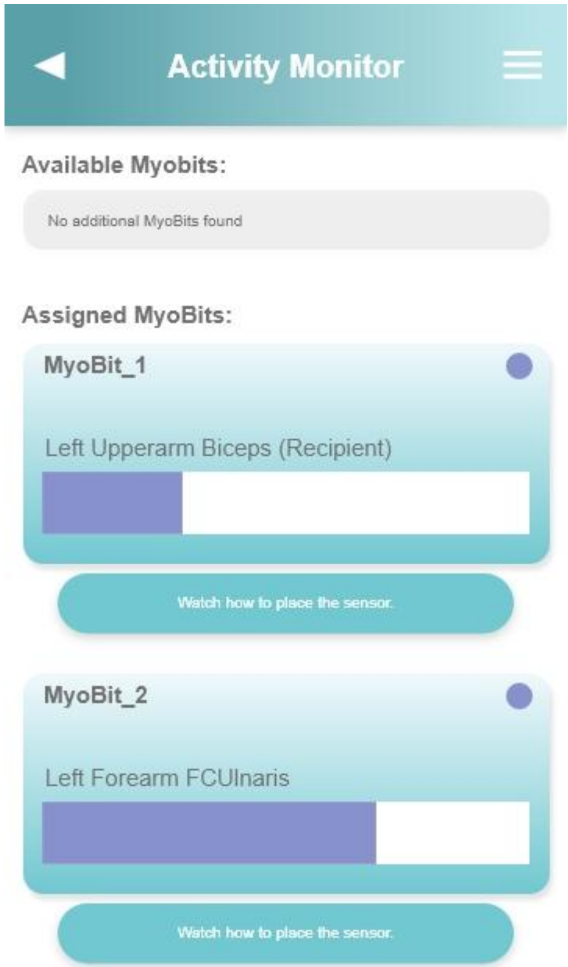

MyoBit_2
Left Forearm FCUlnaris
Donor
Recipient
Watch how to place the sensor.
CONTINUE


CLOSE
Video: Place MyoBit on Biceps

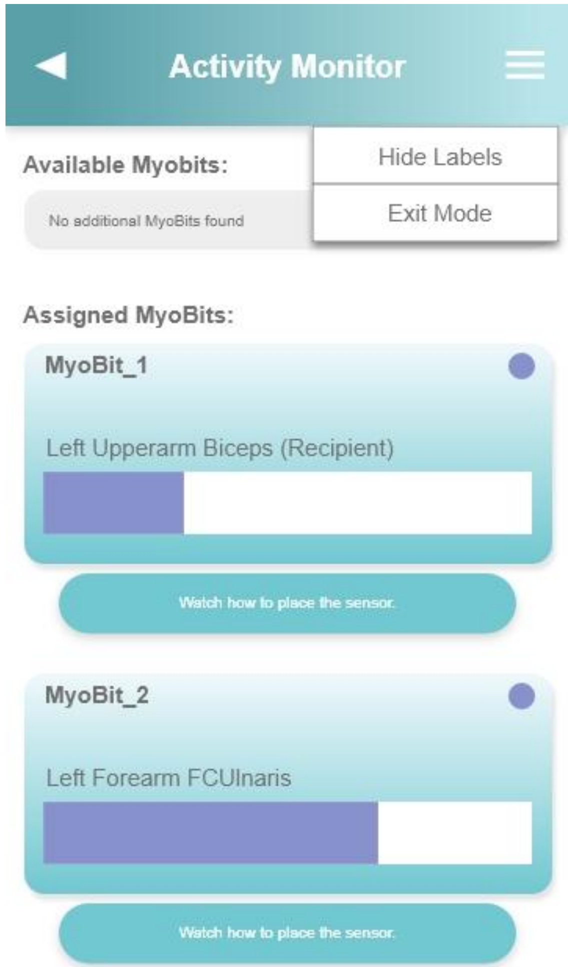

CLOSE
Video: Place MyoBit on Biceps


MyoBit_2
Left Forearm FCUlnaris
Donor
Recipient
Watch how to place the sensor.
CONTINUE


Activity Monitor
Available Myobits:
No additional MyoBits found
Assigned MyoBits:
MyoBit_1
Left Upperarm Biceps (Recipient)
! Sensor not on body ...
Watch how to place the sensor.
MyoBit_2
Left Forearm FCUlnaris
! Sensor not on body ...
Watch how to place the sensor.

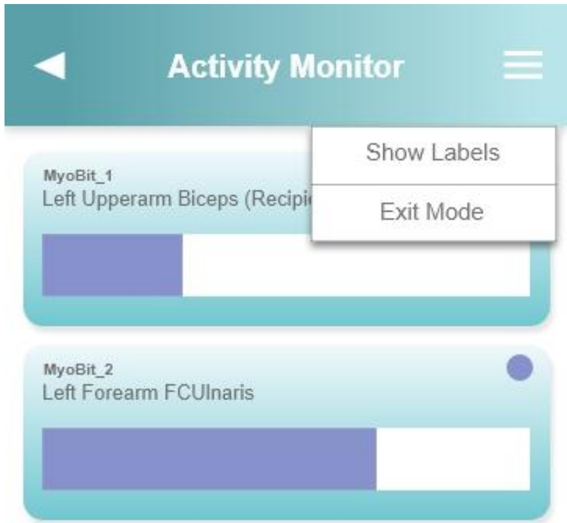


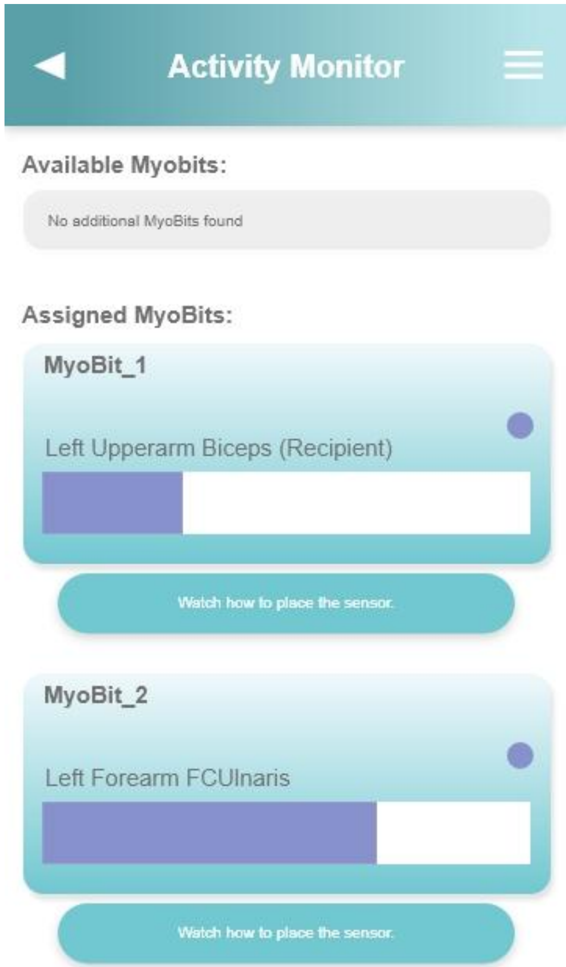
Activity Monitor
Available Myobits:
No additional MyoBits found
Assigned MyoBits:
MyoBit_1
Left Upperarm Biceps (Recipient)
Watch how to place the sensor.
MyoBit_2
Left Forearm FCUlnaris
Watch how to place the sensor.



Activity Monitor
Hide Labels
Exit Mode
Available Myobits:
No additional MyoBits found
Assigned MyoBits:
MyoBit_1
Left Upperarm Biceps (Recipient)
Watch how to place the sensor.
MyoBit_2
Left Forearm FCUlnaris
Watch how to place the sensor.

Activity Monitor
MyoBit_1
Left Upperarm Biceps (Recipient)
MyoBit_2
Left Forearm FCUlnaris


Activity Monitor
Show Labels
Exit Mode
MyoBit_1
Left Upperarm Biceps (Recipi
MyoBit_2
Left Forearm FCUlnaris


Activity Monitor
Available Myobits:
No additional MyoBits found
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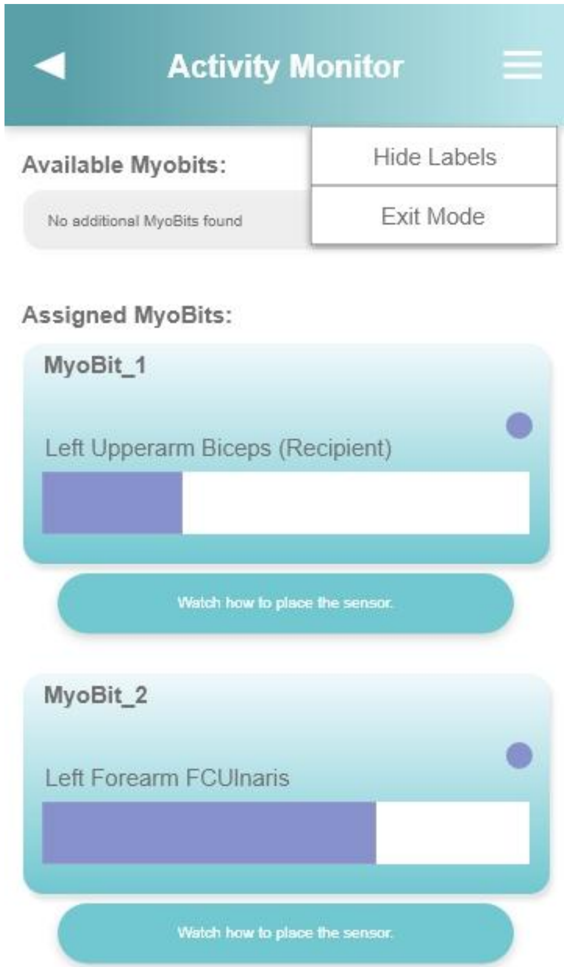
Activity Monitor
Hide Labels
Exit Mode
Available Myobits:
No additional MyoBits found
Assigned MyoBits:
MyoBit_1
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Watch how to place the sensor.
MyoBit_2
Left Forearm FCUlnaris
Watch how to place the sensor.

8. Evaluation

Expert feedback was taken for the mobile application.Theh clickable prototype was presented to the expert therapist after giving a brief description on how the complete product system works.

In the mobile application prototype, we evaluated -

1. Navigation flow
2. Relevance of having two modes - Quick setup mode and Custom setup
3. Interactions for setuping the sensor units and paring them with the mobile application
4. Interactions for choosing one sensor unit and assigning it the target muscle.
5. Selection mechanism for assigning the target muscle for a sensor unit.
6. Relevance of having a horizontal bar graph for visualising real-time biofeedback
7. Relevance of having a marker for maximum action potential displayed by the muscle.

Feedback was taken for each of the above criteria in the application prototype.

9. Conclusion

In India, there are few speciality hospitals which provide proper rehabilitation for Brachial Plexus Injury. After a nerve transfer surgery, BPI patients require special physical rehabilitation which helps them re-educate their muscle. Due to the scarcity of experienced therapists in the field, these patients are bound to spend extra amount on finding the right therapy centre which is mostly away from their hometown. Another problem that we encountered in such therapy centres is that not all of them are able to spend on a special device for biofeedback. Use of biofeedback in such rehabilitation has been mostly of an adjunct therapy type. Despite its effectiveness, not many therapy centres in India are ready to invest on a biofeedback device. This is mainly due to its cost and complex usability.

In this project we addressed the need for an easy to use biofeedback device and an accompanying mobile app that helps both the therapist and the patient during Brachial Plexus rehabilitation. This project has covered the primary design requirements of such a product. This includes the design of an ‘easy to setup and use’ sensor unit, the interactions between the sensor unit and the mobile app, the usability of the app and the challenge to make a common app which can be used both by the therapist and the patient despite the differences in their knowledge of BPI. We do acknowledge that further work can be done in terms of the design of app such that it encourages long term use and have a positive impact on the overall recovery of the BPI patient. Further work on the design of the sensor unit can make it more handy and small. Since this is a design for a medical product, further evaluations on the accuracy, fidelity and safety are a must.

10. References

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