NSF-Prosthesis Project
Phase II Protocol

Ver. 14

Sep. 15, 2022

1. Checklist

a. Equipment and software

No.	List	Check
a-1	Delsys Trigno EMG Sensors and Base Station	☐
a-2	HTC VIVE Pro Eye VR HMD	☐
a-3	HTC VIVE Tracker 3.0	☐
a-4	HTC VIVE Controller (x1)	☐
a-5	HTC VIVE Base Station 2.0 (x2)	☐
a-6	Leap Motion Controller	☐
a-7	Desktop computer for EMG and VR system	☐
a-8	Finger extension/flexion resistance band	☐
a-9	Dynamometer	☐
a-10	Finger extension/flexion exertion device	☐
a-11	Video recorder	☐
a-12	Purdue Pegboard (hand dexterity test)	☐
a-13	Athletic tape	☐
a-14	EMGworks Acquisition software	☐
a-15	Open Broadcast Software	☐
a-16	Virtual reality simulation (Unity)	☐
a-17	Trigno Control Utility software	☐
a-18	MATLAB software	☐
a-19	SteamVR software	☐
a-20	SRanipal Runtime software	☐
a-21	VS Code	☐

b. Handouts

No.	List	Check
b-1	Informed Consent Form	☐
b-2	Demographics questionnaire	☐
b-3	Payment form	☐
b-5	Cognitive workload evaluation form (NASA-TLX)	☐
b-6	Usability evaluation form (USE)	☐
b-7	Simulator Sickness Questionnaire (SSQ)	☐

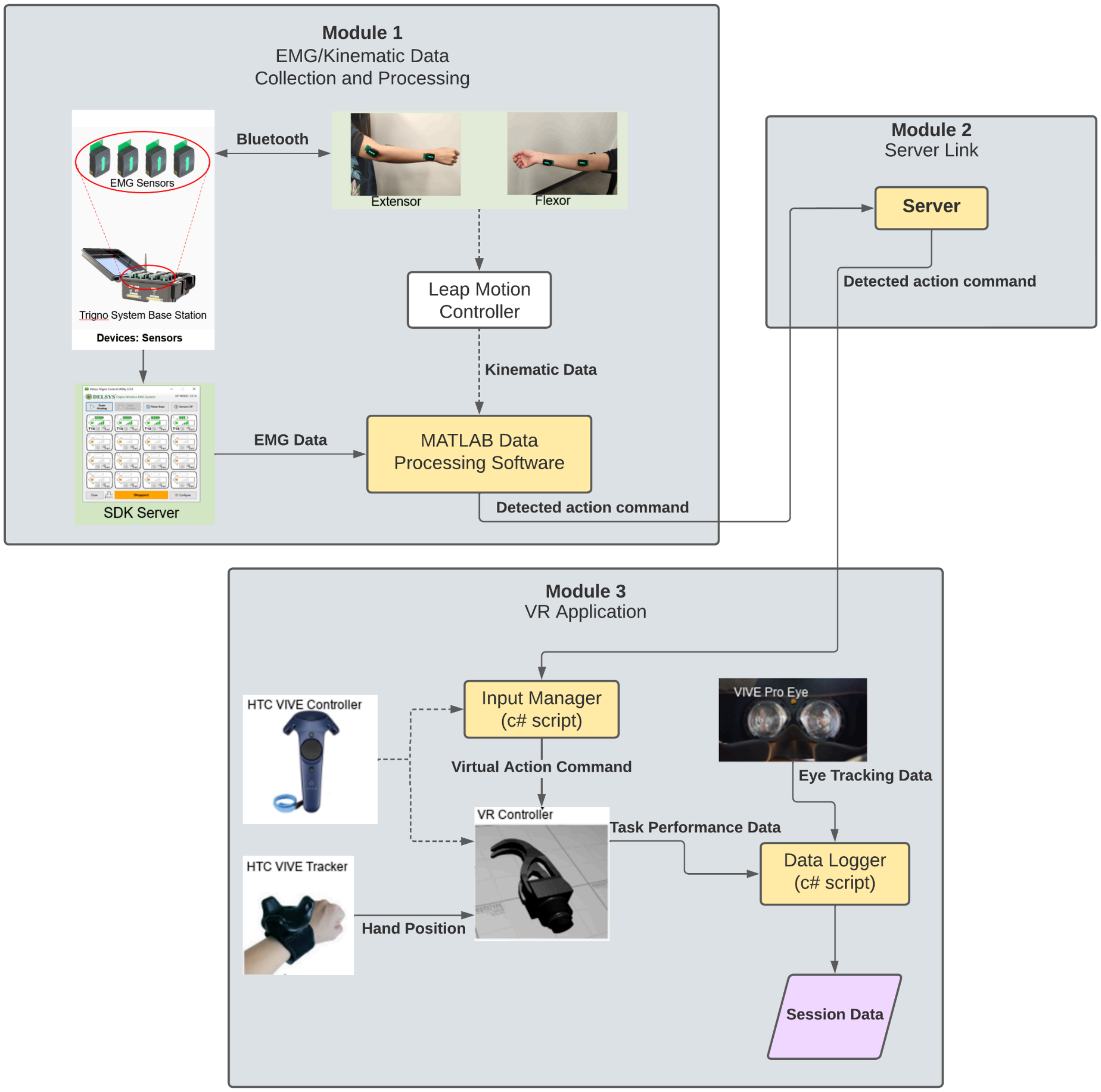
c. Others

No.	List	Check
c-1	Stand for video recording camera	☐
c-2	Disposable wipes and double-sided tape	☐
c-3	Razor for shaving	☐
c-4	Desks, chairs (stationery without armrest), pens, and notes	☐

2. Device preparation

[Hardware and Software Setup Reference]

The schematic below shows the hardware setup for the Phase 2 experiment.



[Precise instructions for EMG device and VR device hardware and software setup are presented below.]

a. Server

[Open VS Code]

[Use VS Code toolbar to open the folder that contains our EMG signal server (UF:C:\NSF-Project-Files\emg-server-python; TAMU:C:\Users\isenadmin\NSF-EMG-HMI\PythonServer\emg-server-python).]

[Type “cd .\Server\ " into the terminal at the bottom of the screen and press enter (if no terminal is present, open a new one with Terminal > New Terminal with the toolbar at the top of the screen.]

[Type “python Program.py” into the terminal and press enter. When using the CC method, type “python Program.pc -c” to put the server into the proper mode.]

[If you receive the error: “OSError: [WinError 10048] Only one usage of each socket address (protocol/network address/port) is normally permitted”
It means the server hasn’t been properly terminated on the port number (8080).
This can be solved by killing the process running on the port.
On windows: Open Command Prompt (CMD) as ADMINISTRATOR

```
>netstat -ano | findstr :<PORT>
  TCP    0.0.0.0:8080           0.0.0.0:0              LISTENING       7560
>taskkill /PID <PID> /F
Should then show: SUCCESS: The process with PID 7376 has been terminated.
```
]

[Check that the terminal prints messages “Waiting for client connection…” and “Waiting for EMG connection…”.]

The server is now running.

If for any reason the server must be restarted, kill the terminal with the trashcan icon in the upper right of the terminal window and repeat the steps above in a new terminal in VS Code.

b. EMG sensors

The following hardware and software are integrated as part of this subsystem:

- Control computer
- EMG hardware – Delsys Trigno (Delsys Inc., Boston, MA)
- EMG software – EMGworks Acquisition, Trigno Control Utility (Delsys Inc., Boston, MA)
- Leap Motion Controller
- MATLAB software

[Confirm that Delsys Trigno base station is connected to the power supply and that station is unobstructed.]

[Confirm that Delsys Trigno base station is connected to control computers through USB cable and the unit is unobstructed.]

[Confirm that the connection signal between Delsys Trigno base station and EMG sensors is strong and stable.]

[Confirm that the control computer is connected to the power supply and the unit is unobstructed.]

[Open EMGworks Acquisition and MATLAB software (PR: prTrainApp.mlapp; DC: dcApp.mlapp; CC: main.m) on control computer]

[Confirm Leap Motion Controller is connected to a USB port and the computer recognizes it]

[Click on "EMG-HMI Project Config" in EMGWorks Acquisitions]

[Click Load and Edit >, then click Start]

[Use unique participant <u>id#_trial#_mmddyyyy</u> as the name of the run]

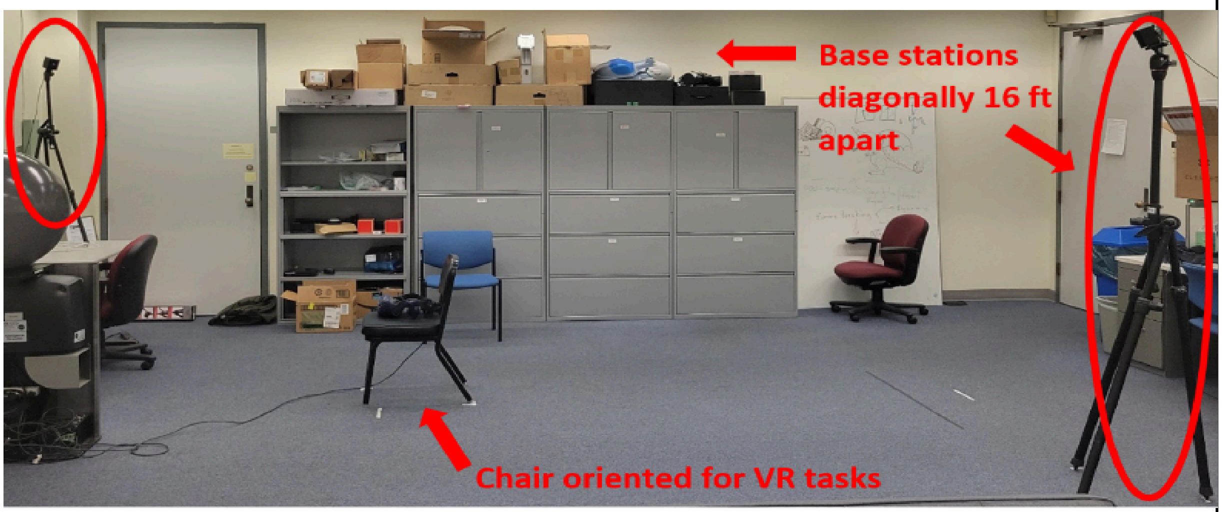
[Set "Target Folders for Acquired Data (folder name: EMG Subject Data Raw)" to the desired folder, click "Okay"]

[Ctrl + click and drag to scale plots to 400uV range]

c. VR device

<u>The following hardware and software are integrated as part of this subsystem:</u>

- VIVE Pro/VIVE Pro Eye software (SRanipal Runtime)
- VIVE Base Station 2.0 (x2)
- Steam and SteamVR
- HTC VIVE Tracker 3.0 and Controller
- Athletic tape
- VR Simulation (Unity)



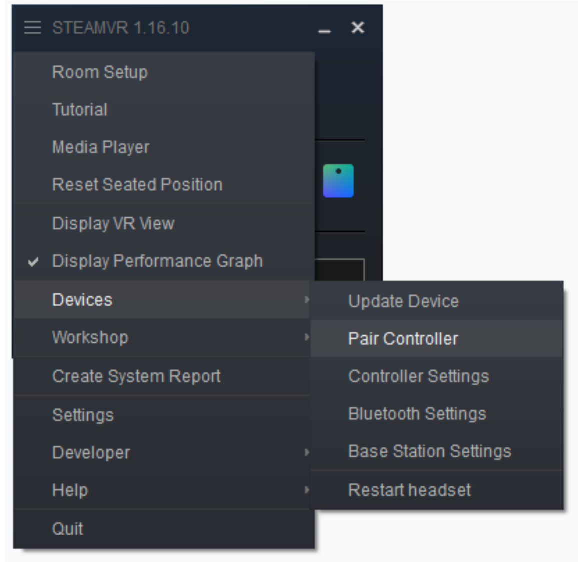
[Confirm that base stations are powered and unobstructed.]

[Confirm that VIVE Pro headset is powered from link box (blue button)]

[Open SteamVR]

[Confirm that VIVE Tracker is paired on SteamVR.]

[To pair VIVE Tracker, refer to the image below. In the SteamVR window, select the menu stack icon in the top left -> Devices -> Pair Controller.]



[Confirm that eye tracking is enabled on VIVE System Dashboard (VR screen that a participant can see) and SRanipal is running in the system tray (Robot head icon should turn to green).]

[Open VR simulation program. BE CAUTIOUS!!! DO NOT UPDATE THE SOFTWARE. JUST CLICK "X" ICON AT THE TOP-RIGHT CORNER OF THE POP-UP WINDOW]

3. Orientation

[An experimenter must read to a participant all text appearing in *italics* in the following tables.

a. Introduction to experiment

[Escort participant to the lab] *Thank you for participating in this experiment. The objective of this research is to identify differences in cognitive workload of using different EMG-based human-machine interfaces in a virtual reality simulation. Please know that this experiment is not a test of your personal abilities or upper-limb movement skills.*

b. Informed Consent Form

[Prepare informed consent form and pen] *This form summarizes the information you need to know about the experiment. Please read the document and feel free to ask any questions you may have.* **[Allow participant time to read the form]** *If you consent to participate in this study, please sign and date the form.* *Before we begin the experiment, I need you to turn off your cell phone in order to prevent distractions during training and actual experiment trials.*

c. Demographic questionnaire (DQ)

[After participant signs the informed consent form, present DQ] *Now you will complete a background questionnaire.* **[Verify the participant completes all information correctly. Once complete, enter the participant number at the end of the form.]**

d. Briefing on procedure and tasks

There are two phases to this experiment. The first phase involves training, and the second phase is the actual VR system test. *In this experiment, you will use EMG sensors and a VIVE tracker to perform virtual activities of daily living (ADL)* **[POINT OUT the EMG sensors and VIVE tracker.]** *In order to familiarize you with the system devices, you will be trained in specific upper-limb (preferred/dominant hand) and hand motions. Subsequently, you will be trained on the ADL tests used in this study. Once you pass the training, you will perform the tasks as part of the actual experiment. There are two tasks as part of this study: (1) CRT (Clothespin relocation task) and (2) SHAP (rotating a door handle task).*

4. Training session

a. Handness and Dexterity assessment

1. Handedness assessment

[If participants passed this before they came to the lab, then, this assessment can be skipped]

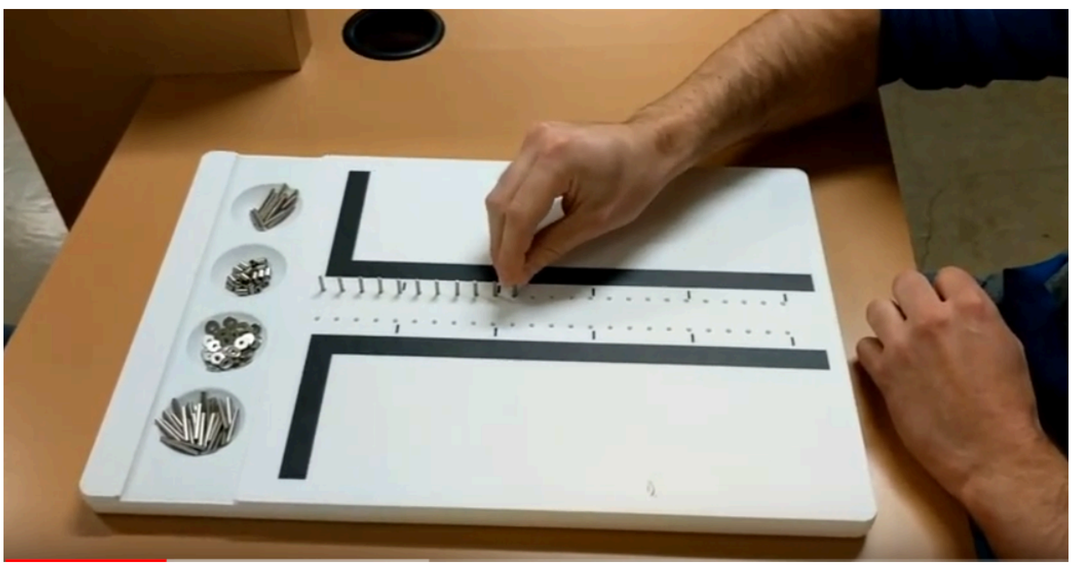
[Have the Edinburgh Handedness Test (EHT) ready on the PC. Link: http://www.brainmapping.org/shared/Edinburgh.php#] Reference: Oldfield, R.C. "The assessment and analysis of handedness: the Edinburgh inventory." Neuropsychologia. 9(1):97-113. 1971.

This quick survey will help us identify whether you are right handed so we can continue with the study. Please fill out this online form.

[The participant can complete the experiment if his/her right-hand dominance score is 70% or greater]

2. Dexterity test (Purdue Pegboard Test; PPT)

Now we would like to assess your dexterity level by using the Purdue Pegboard Test. **[Show the participant the PPT setup.]**



[A participant needs to complete this assessment three times. Record the number of pins inserted in each trial. Calculate the average of these values and compare it with the table below to assess the participant's dexterity level.]

[Begin by saying and demonstrating…]

Pick up one pin at a time with your right hand from the right-side cup. Starting with the top hole, place each pin in the right-side row. (Leave the pin used for demonstration in the hole.) Now you may insert a few pins for practice. If during the testing time you drop a pin, do not stop to pick it up. Simply continue by picking another pin out of the cup.

[Correct any errors made in placing the pins and answer any questions. When the subject has inserted three or four pins and appears to understand the operation, say:]
"Ok. Now please take out the practice pins and put them back into the right-side cup."

[After the subject completes this task, say:]
"When I say 'Begin,' place as many pins as possible in the right-side row, starting with the top hole. Work as rapidly as you can until I say 'Stop.' Are you ready? Begin."

[Start timing when you say:]
"Begin."

[At the end of exactly 30 seconds, say:]
"Stop."

[Count the number of pins inserted and record the score. This is the score for the participant's preferred hand.]

[Repeat this exercise twice to get 3 values for the right-hand score.]

[If the average PPT score is no more than one standard deviation below the normal mean dexterity for their age and gender group, the participant can perform the experiment.]

Table 14-22
Mean Performance of Young Adults for the Purdue Pegboard (One Trial Per Subtest)

	Age Groups				
	15-20	21-25	26-30	31-40	15-40
Females					
n	30	36	16	16	98
Preferred Hand	16.69	16.64	17.25	15.94	16.64
SD	2.16	2.31	1.38	1.61	2.10
Nonpreferred Hand	16.10	15.89	16.13	15.63	15.95
SD	1.57	1.79	1.50	1.89	1.68
Both Hands	13.76	13.75	13.31	13.13	13.58
SD	1.41	1.54	1.45	1.31	1.45
Assemblies	41.83	42.47	40.44	41.44	41.77
SD	5.08	5.43	5.90	5.75	5.42
Males					
n	32	37	32	26	127
Preferred Hand	15.56	15.44	16.22	15.35	15.65
SD	1.52	1.71	1.81	1.72	1.71
Nonpreferred Hand	15.09	15.08	15.41	15.12	15.17
SD	1.42	1.98	2.08	1.77	1.82
Both Hands	12.59	12.97	12.94	12.42	12.75
SD	1.56	1.18	1.29	1.65	1.42
Assemblies	40.25	38.89	39.13	37.50	39.01
SD	4.64	6.60	3.58	3.64	4.92

Note: Data were compiled from 225 healthy adults, largely right-handed (87.7%), with above average IQ, residing in a large city in Western Canada.

b. EMG device setup and maximum voluntary contraction (MVC)

[PR & CC: Sensor 1-4; DC: Sensor 1 & 2 only]

EMG sensors will be placed on your skin one by one via double-sided tape placed over the muscles that extend and flex your fingers to measure physiological responses when you move your arm and hand. Before placing these sensors, I need to shave the hair on your arm. Also, I need to clean the skin with a wipe containing alcohol. The wipes and double-sided tape we use are hypoallergenic, and the razor is thoroughly disinfected for each experiment.

At the same time, in order to facilitate the standardized processing of our data, we need to measure the MVC (Maximum Voluntary Muscle) of the corresponding muscle with each sensor. Each muscle needs to be measured 3 times. For the same muscle, there will be a 1-minute rest period between each measurement. I will explain and demonstrate how to use the device to extend or flex your muscles, respectively.

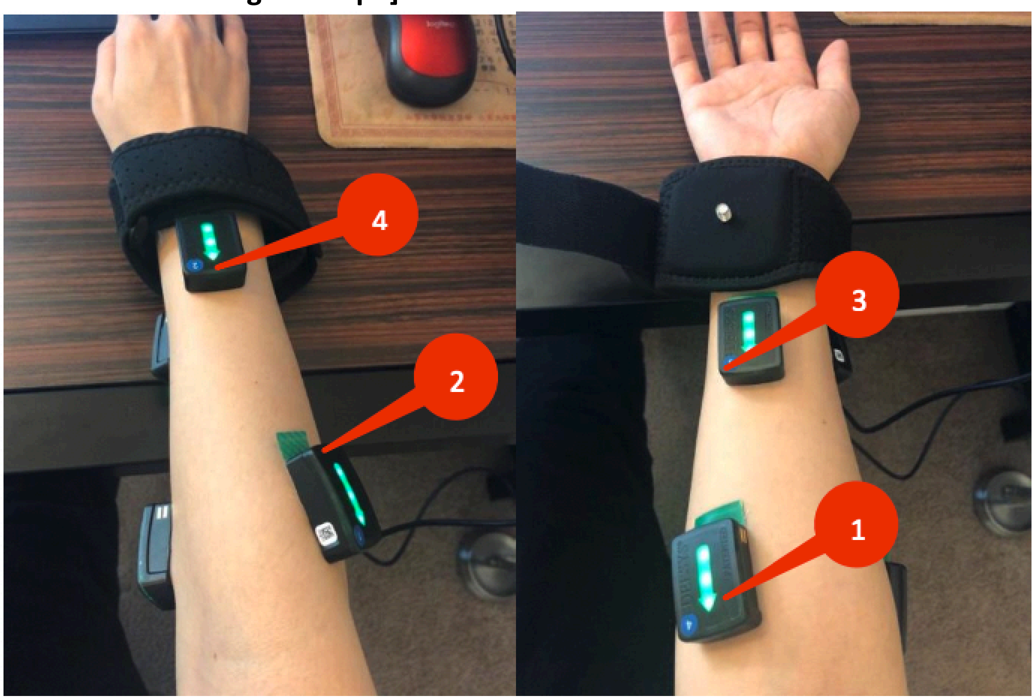
[Ask participants if they want to go to the restroom, to avoid losing the connection between sensors and Trigno device]

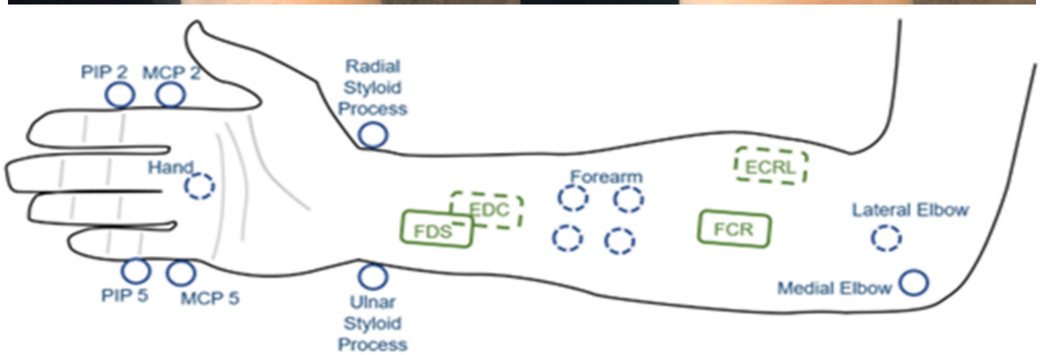
[Identify EMG device]

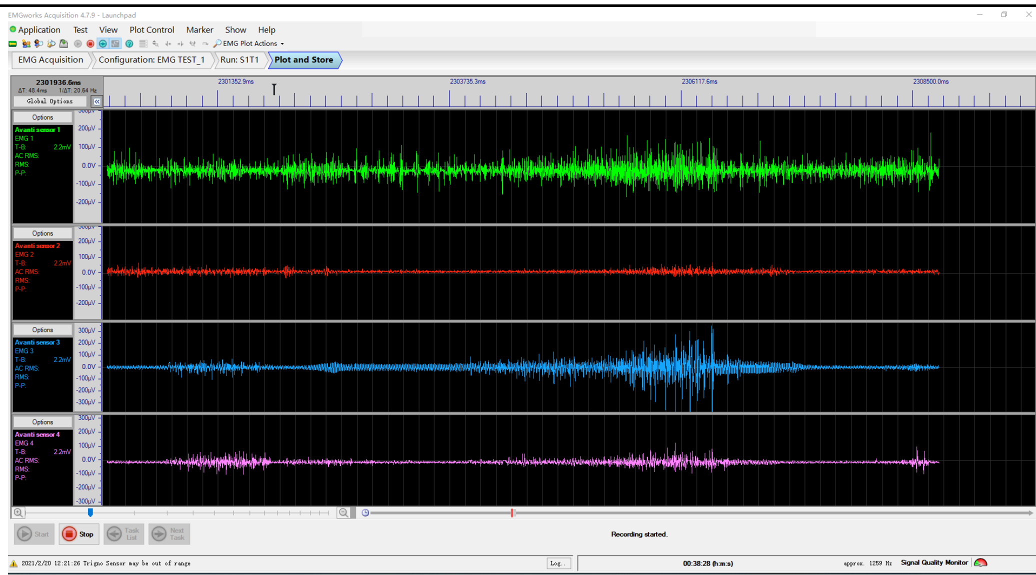
[Please refer to the device setup above.]

[Open EMGworks Acquisition by double-clicking the desktop icon]

[Sensor location and signal shape]







1. **[Sensor 1: Flexor carpi radialis (FCR) - DC/PR/CC]**
   a. Click “Start” to begin EMG detection and place the first sensor on the participant's arm.

Participant: The participant should be seated, and the experimenter should hold the participant's wrist with their palm facing up. The wrist is in a neutral position or slightly extended, and the experimenter is holding the weight of the lower arm, allowing the participant to focus on making the required movement.

Experimenter: Once the participant is ready, hold the participant’s wrist and ask him/her to flex their wrist upward, bringing the palm toward their body. Use the other hand to locate muscle with two fingers.

Repeat this action until the identification of a position with good muscle movement. Then, swipe the bottom of the sensor with an alcohol swipe pad, place it on the position, and hold the first sensor without a sticky pad. After checking a stable and clean signal pattern, place two fingers around the sensor to make sure of the position, then, another experimenter should put a sticky pad on the bottom of the sensor. Then, place the sensor between the two fingers. The direction of the arrow on the sensor should be towards the participant’s body. Repeat muscle flexion instructions to ensure clean signals after the sensor has been placed.

When I say “Go” please flex your wrist upward and try to bring your palm toward your body. When I say “relax”, relax your wrist. I will repeat these commands a few times to locate the muscle.

Experimenter: Click “Stop” and “Next Task” to open the MVC collection configuration.

   b. Measure MVC

Position: During MVC measurement, a participant should place the feet on the dynamometer chassis as shown in the picture. Ask the participant to place his or her right arm on the right leg and grip the handle with the palm of the right hand **facing up**. The experimenter then adjusts the length of the chain so that the participant can still tense the chain while the muscles relax. Then, start the measurement.

*For this exercise, three measurements will be taken, and the maximum value will be recorded. In each measurement, when you hear "five, four, three, two, one, begin!" from me, you need to **flex** your wrist as much as you can. When you pull it, please do not raise or use your foot or ankle. You only need to use your upper-limb muscle. Make sure this and hold that upper-limb power for 3 seconds until you hear "You can stop, now". Then, you can then relax for 1-minute This process will be repeated 3 times.*

Experimenter: Once the participant is ready, click the "Start" button. At the end of the exercise, the experimenter needs to press the "Stop" button and record the MVC value in "mvc_offset.xlsx". Click "Next Task". If there are some discontinuities or unreasonably high peaks due to sudden movement within the MVC range, move the range to measure a sound signal.

[Add MVC information in the Google sheet]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

2. **[Sensor 2: Extensor carpi radialis longus (ECRL) - DC/PR/CC]**
    a. Click "Start" and place the second sensor on the participant's arm.

Participant: The participant should be seated, and the experimenter should hold the participant's wrist with their palm facing down. The wrist is in a neutral position or slightly extended, and the experimenter is holding the weight of the lower arm, allowing the participant to focus on making the required movement.

Experimenter: Once the participant is ready, ask him/her to extend their wrist upward, bringing the back of their hand toward their body. Use the other hand to locate muscle with two fingers. Repeat this action until the identification of a position with a good and stable signal pattern, then put it on the second sensor. Click "Stop" and "Next Task''.

When I say "Go" please flex your wrist upward and try to bring the back of your hand toward your body. When I say "relax", relax your wrist. I will repeat these commands a few times to locate the muscle.

b. Measure MVC

Position: Participant should place their feet on the dynamometer chassis as shown in the picture. Ask the participant to place his or her right arm on the right leg and grip the handle with the palm of right hand **facing down**. The experimenter then adjusts the length of chain so that the participant can still tension the chain while the muscles relax. Then start the measurement.

*For this exercise, three measurements will be taken, and the maximum value will be recorded. In each measurement, when you hear "five, four, three, two, one, begin!" from me, you need to **extend** your wrist as much as you can. When you pull it, please do not raise or use your foot or ankle. You only need to use your upper-limb muscle. Make sure this and hold that upper-limb power for 3 seconds until you hear "You can stop, now". Then, you can then relax for 1-minute This process will be repeated 3 times.*

Experimenter: Once the participant is ready, click the “Start” button. At the end of the exercise, the experimenter needs to press the “Stop” button and record the MVC value in “mvc_offset.xlsx”. Click “Next Task”.

[Add MVC information in the Google sheet]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

3. **[Sensor 3: Flexor digitorum (FD) - PR/CC]**
    a. Click “Start” and place the third sensor on the participant's arm.

Participant: The participant should be seated and the experimenter should hold the participant's wrist with their palm facing up. The wrist is in a neutral position or slightly extended and the experimenter is holding the weight of the lower arm, allowing the participant to focus on making the required movement. The metacarpophalangeal (MP) joints and interphalangeal (IP) should be in a relaxed and slightly flexed posture.

Experimenter: Once the participant is ready, ask him/her to make a fist and repeat this action until the identification of a position with a good and stable signal pattern, then put on the third sensor. Click “Stop” and “Next Task''.

When I say “Go” please make a fist and squeeze. When I say “relax”, relax your hand. I will repeat these commands a few times to locate the muscle

The experimenter can also instruct the participant to repeatedly touch their middle finger to their palm to check for clear signals. The fist–squeeze method typically elicits larger signals, however.

    b. Measure MVC

Participant: The participant should be seated. Ask the participant to hold the device, as shown in the picture with their arm at their side.

For this exercise, three measurements will be taken and the maximum value will be recorded. At the beginning of each measurement, when you hear the beep, you need to use the grip-strength measurement device to flex your fingers as much as you can. Hold this position for 3 seconds until you hear the beep again. You can then relax for 1-minute rest until the beep for the next measurement begins. This process will be repeated 3 times before completion of the exercise.

Experimenter: Once the participant is ready, click the “Start” button. At the end of the exercise, the experimenter needs to press the “Stop” button and record the MVC value in “mvc_offset.xlsx”. Click “Next Task”.

[Add MVC information in the Google sheet]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

4. **[Sensor 4: Extensor digitorum (ED) - PR/CC]**
    a. Click “Start” and place the fourth sensor on the participant's arm.

Participant: The participant should be seated and the experimenter should hold the participant's wrist with their palm facing down. The wrist is in a neutral position or slightly extended and the experimenter is holding the weight of the lower arm, allowing the participant to focus on making the required movement. The metacarpophalangeal (MP) joints and interphalangeal (IP) should be in a relaxed and slightly flexed posture.

Experimenter: Once the participant is ready, ask him/her to make the gesture of pressing piano keys and repeat this action until the identification of a position with a good and stable signal pattern, then put on the fourth sensor. **Click “Stop” and “Next Task''.**

When I say “Go” please move your fingers as if you are playing the piano. When I say “relax”, relax your hand. I will repeat these commands a few times to locate muscle

    b. Measure MVC

Participant: The participant should be seated. Ask the participant to don the finger straps as shown in the picture, and hold their arm on its side.

For this exercise, three measurements will be taken, and the maximum value will be recorded. At the beginning of each measurement, when you hear the beep, you need to extend your fingers against the resistance bands as much as you can. Hold this position for 3 seconds until you hear the beep again. You can then relax for 1-minute rest until the beep for the next measurement begins. This process will be repeated 3 times before completion of the exercise.

Experimenter: Once the participant is ready, click the “Start” button. At the end of the exercise, the experimenter needs to press the “Stop” button.

[Add MVC information in the Google sheet]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

[Close EMGWorks Acquisitions software. Open Trigno Control Utility.]

[Open Trigno Control Utility > Configure > Digital Output > Uncheck backwards compatibility > Keep the Trigno Control Utility ope[n]

5. **Calibration on input gain**

At first, you will have a VIVE tracker placed on your wrist in order to track your hand movement. (Please place the palm of your right hand on the table, and athletic tape will be used to secure the tracker in place) Please put on a glove to secure the tracker in place.

[Place the VIVE tracker in a centered position on the back of the hand.]

[Wrap athletic tape around the hand twice to secure the tracker]
or
[Hand a glove to the participant]

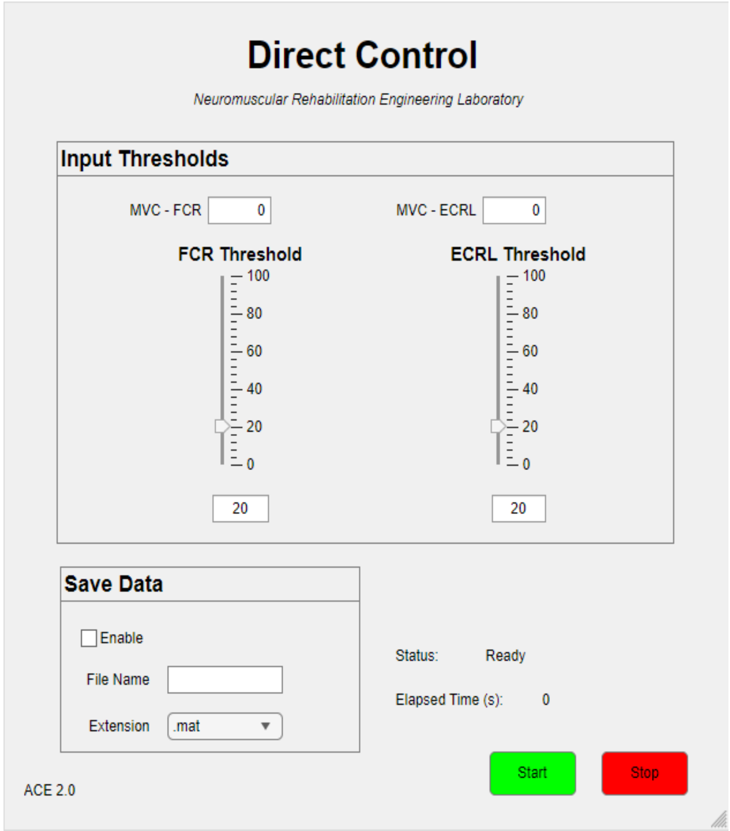
[Ensure participants can open and close their hands. Repeat the taping procedure if movement is constricted.]

[Prior to each task or new instantiation of the Unity application, you MUST create a new log file. Log files are not automatically created unless initiated by the operator.]

a. DC

[Open dcApp.mlapp > Assign the appropriate threshold values > Click on the "Enable" data box and enter file name > Press Start to begin]

[To set thresholds, begin by raising both thresholds by 5% until the output action is inactive. Then lower FCR threshold by increments of 5% until close/pronate outputs are observed when performing flexion. Also perform extension to make sure the intended action is not triggered by the opposing action. If it is difficult to return to the inactive state, progressively raise the threshold by 1% until control is established. Repeat this process for ECRL threshold. Once close/pronate and open/supinate control is established, practice co-contracting to switch active DOF. Lower both thresholds by 1% if co-contraction is difficult and repeat if necessary. An alternate co-contraction method is to make a fist and perform flexion simultaneously if making a fist is not enough to trigger the co-contraction. (Tip: To change the mode with the contraction (i.e., making a fist), you need to squeeze with your arm strongly)]



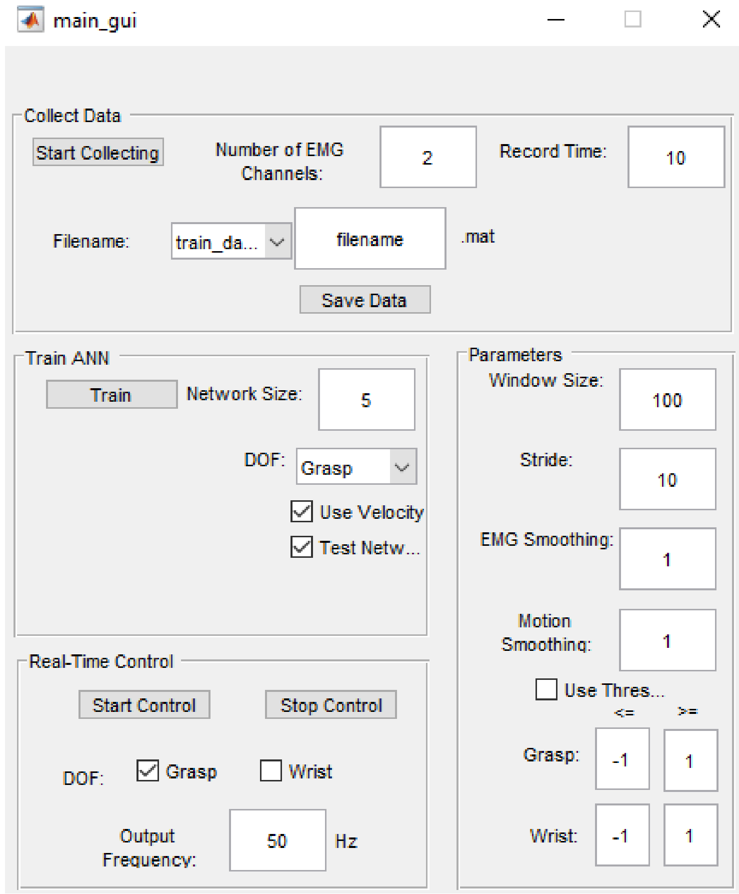
[Add MVC% information in the Google sheet]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

b. CC

[Open main_gui.m > Click on Start Collecting to collect data > Click on Train to train the neural network > Press Start to begin]

CC training
30 seconds record time
Change filename for each one
Train both Grasp and Wrist

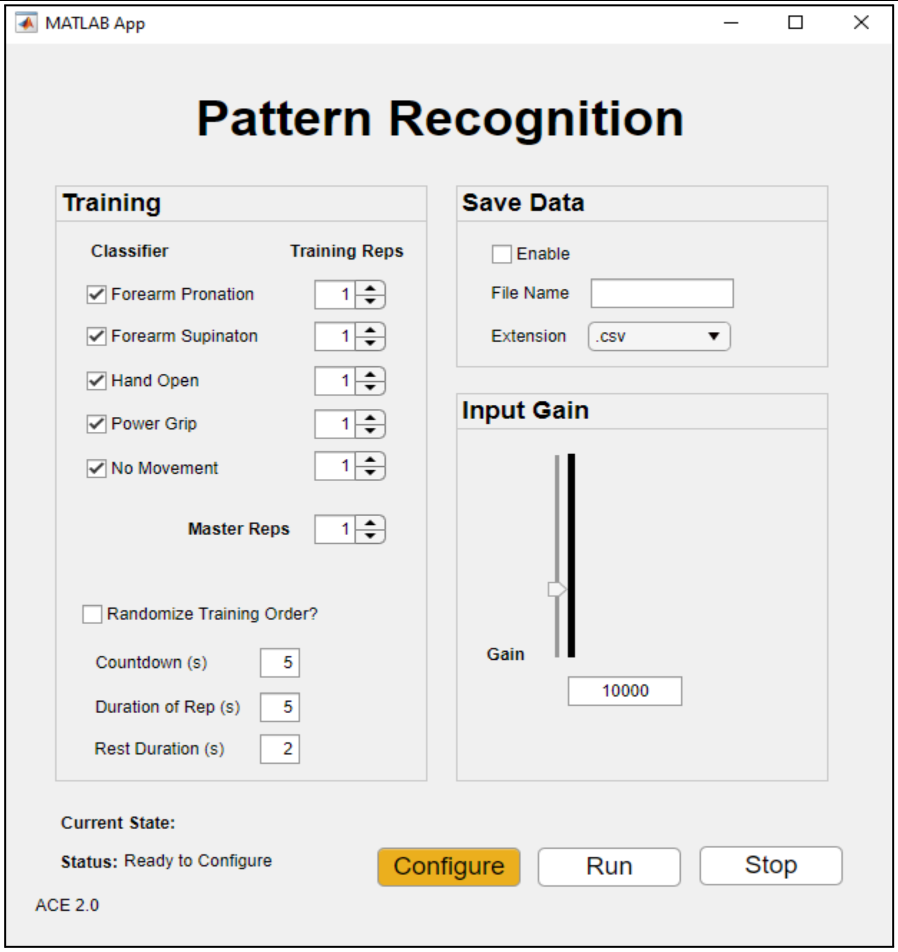
Pattern data: fingers always stay together
1st -> open neutral close per beat
2nd -> pronate neutral supinate per beat
3rd -> only fingers, whatever the participant wants
4th -> only wrist, whatever
5th -> random motion with hand/wrist/fingers



c. PR

[Open prTrainApp.mlapp > Click on the appropriate MVC to collect > Click on the "Enable" data box and enter file name > Press Configure to begin]

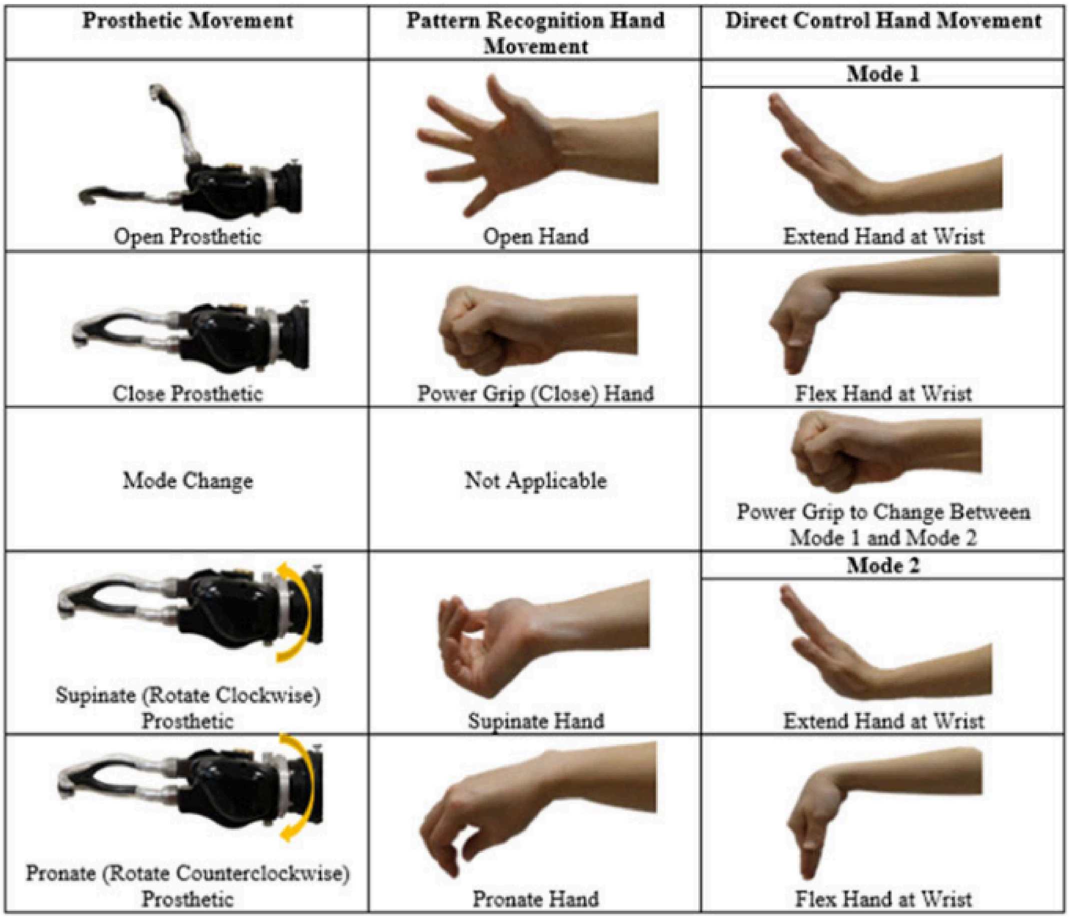
[Training may require multiple sessions before a usable model is formed.
Prior to collecting data, instruct the participant on the procedure:
>There are 5 unique modes.
>For pronate and supinate, perform each action while keeping your fingers in a neutral position.
>For open and close, perform each action while keeping your arm in a neutral position.
>For the inactive position, keep your entire arm in a neutral position.
>When the first image showing the red bar shows, remain inactive.
>Once the green bar shows, immediately move into position.
>How much force should I apply? Each action should be performed in a relatively natural manner. Straining your muscles could result in multiple control modes being recognized at the same time and a poor model.
>Once data collection is complete, the GUI will print "Calc Features"
>If the GUI shows "Model not formed!", then no data was collected and the system needs to be restarted.
>Once the GUI shows, "Model formed!", you are ready to run.
>Make sure the python server is connected (should have been by now).
>Prior to testing the system on unity, make sure the participant can achieve all modes (most importantly open). If not, the model may need to be retrained.



c. Introduction to different types of virtual prosthetic devices

Participants should be seated for this phase of the study.

[Training on the virtual prosthetic device configurations: DC, PR, and CC]
*** We Need to explain only one of three, as the participant will only be assigned one configuration.**



For those participants assigned to the DC mode: [DC]
In this training session, you will use a virtual simulation of a direct-control (DC) interface. There are ***two modes*** *and* ***three gestures*** *for the use of this device*. ***[POINT OUT THE FIGURE]****. In one mode, you can only open or close the hook by doing flexion and extension. In another mode, you can rotate the hook clockwise or counter-clockwise by doing the same gestures. To change the mode, as you can see here, you need to make a fist. You will be allowed to practice controlling the device until you report comfort with the DC control. Subsequently, you will advance to the task-specific training period.*

For those participants assigned to the PR mode: [PR]
In this training session, you will use a virtual simulation of a pattern recognition (PR) interface. There are four hand gestures for the use of this device. ***[POINT OUT THE FIGURE]*** *You will be allowed to practice controlling the device until you report comfort with the PR control. Subsequently, you will advance to the task-specific training period.*

For those participants assigned to the CC mode: [CC]
In this training session, you will use a virtual continuous control (CC) interface. You will be required to continuously switch between four hand gestures **[POINT OUT the FIGURE above].** *You will be allowed to practice controlling the device until you report comfort with the CC device. Subsequently, you will advance to the task-specific training period.*

[Ask participants to don the headset after studying the figure.]

[Bring up Unity]

[Enter participant number > Connect to server > Select configuration, trial, and task type > Click "Load VR Scene"]

[When the participant reports comfort with the configuration, press the "Esc" key to reload the VR application to the main menu.]

[Ask participants to remove the headset]

d. VR Device Setup

1. VR environment setting selection

[Open Steam (just Steam) to check if the account is correct (TAMU: tamu_hsi_lab;UF: ruizlab). Then, minimize it.]

[Before participant arrives, sit in the chair and put on the VR headset. Open the VR menu with the controller menu button and select "Reset Standing Position" in the lower right corner to synchronize VR orientation to seated position. The experimenter can do this on behalf of the participant pulling the trigger in the VIVE controller]

[Open the Unity application to access the VR environment's main menu, shown below.]

[Click the play icon at the top to initiate the main GUI]

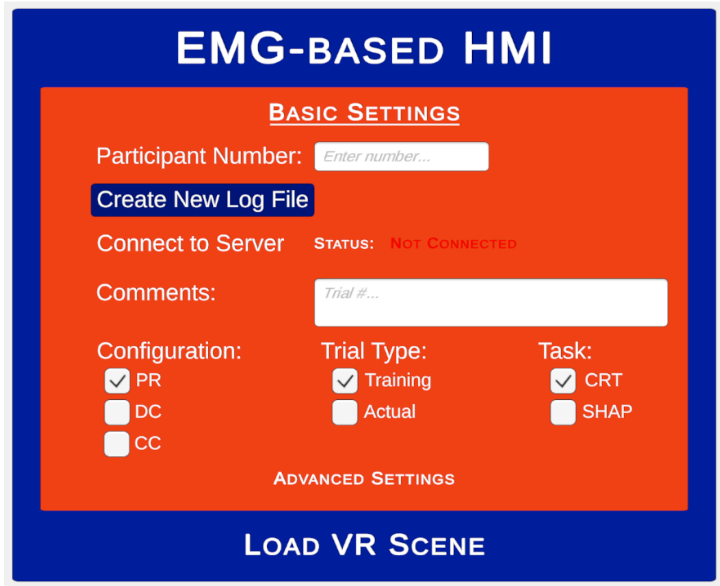
Now, you will train with the VR controller for the ADL tests used in this study.

[Enter participant number and select EMG device configuration]

[Select "Training" as trial type and select the task to train]

[Click the "Connect to Server" button to connect to the server receiving the EMG signal input.]

[Advanced settings do not need to be changed for this experiment.]



Notation for Participant Number: mmddyyyy (e.g., 08242022)
Notation for Comments: (Participant Number)_(Task)_(Trial Type)_(Trial Number) (e.g., p01_crt_actual_02, p12_shap_training_07…)

2. VR controller setup & Eye tracking

Before entering the testing environment, we need to perform a calibration procedure for the eye-tracking software.

Now, you will be provided with an opportunity to orient yourself to the VR testing environment.

[Point out VR headset.]

[Place the headset on the participant.]

[Start the Open Broadcast Software (OBS) recording.]

[Bring the SteamVR pop-up window and click "Display VR" in the menu.]

[Check if SRanipal runs (Robot head icon in the system tray)]

[The experimenter will need to turn on a regular VIVE controller to access the System Dashboard with the Steam Menu button. The experimenter will navigate the menu using the controller while the participant wears the VR headset. See the small button just below the large circular trackpad. Select "VIVE Pro Eye" on the dashboard. Confirm "Use eye tracking" is enabled and select "Calibrate". Instruct the participant to complete the eye-tracking calibration by following the dot with their eyes as it moves to 5 calibration locations on the screen. Press the Steam Menu button again to close the menu. Turn the controller used for menu navigation off and set it aside. Ask the participant to remove the headset.]

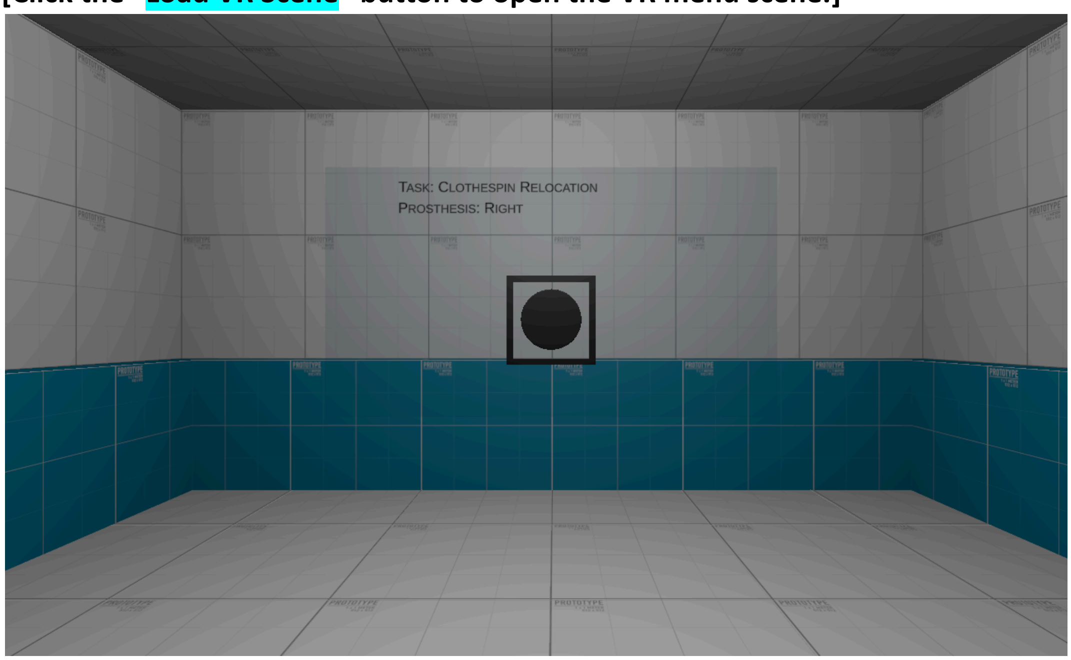
e. Training session

Participants should be seated for this phase of the study.

➢**DO NOT FORGET** to use a video recorder to capture both **Unity** screen and participants' **hand gestures** together. **DO NOT** capture participants faces.

[Baseline pupil size - before the first training trial]

[Click the "Load VR Scene" button to open the VR menu scene.]



[The VR menu scene shown above will be visible on the screen for the researcher and in VR for the participant.]

[Now, the baseline participant pupil size must be recorded. Instruct the participant to focus on the large gray circle on the information panel in front of them.]

This is the testing environment. We will now record your pupil size in your relaxed state. Please look at the large gray circle located within the gray square on the screen in front of you. The circle will turn black when the system detects that you are looking at it. When asked, please continue to focus on the circle and breath calmly for the duration of the collection period (2 minutes). The gray square will turn black and remain black for the duration of the pupil collection procedure. After 2 minutes, you will see a "Task completion" message on the screen and also hear a "ding!" noise from your VR headset.

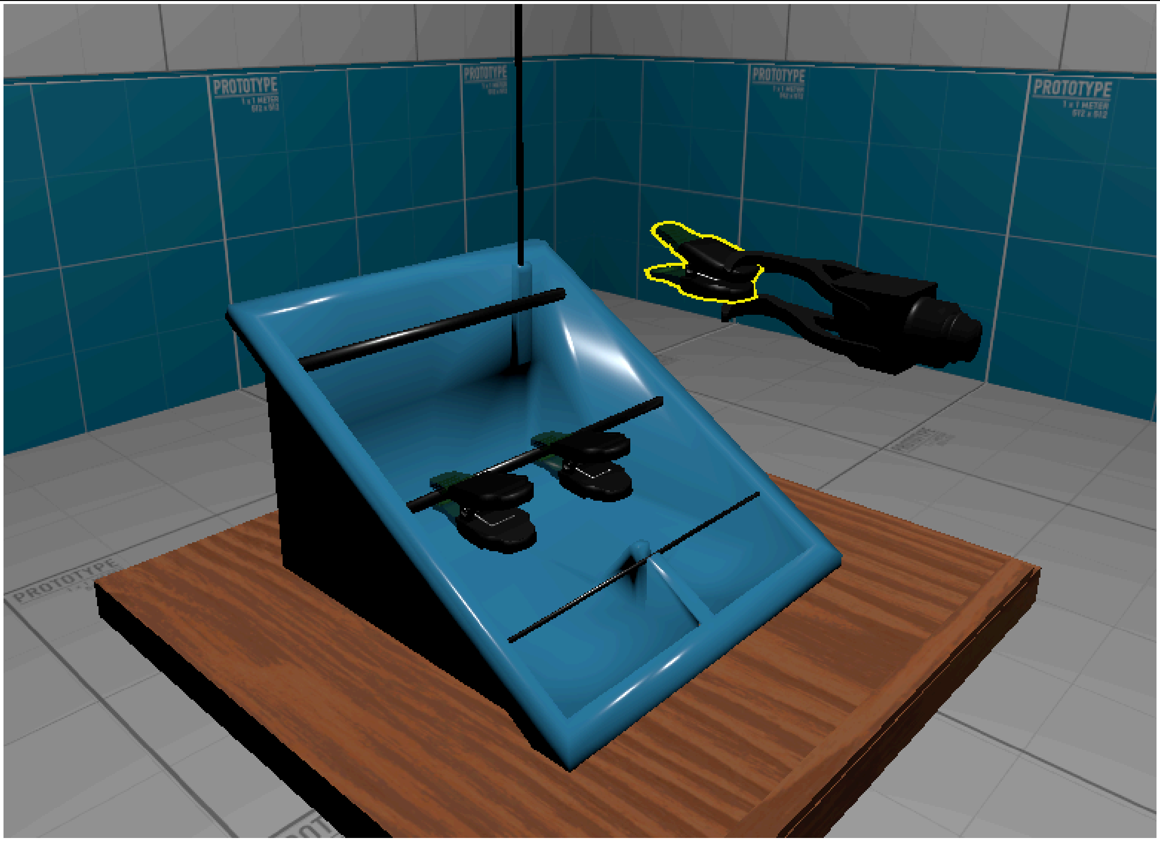
[When the participant is ready, press the 'P' key on the keyboard to begin a 2-minute recording of the pupil size.]

[After this 2-minutes recording, the participant needs to take the headset off and have a 2-minutes rest.]

➢ **If the Unity clock (120 seconds) does not work, close Unity, VS Code, and MATLAB APP and rerun again**

[Training on the virtual ADL Tasks: CRT and SHAP]

[CRT]



[Press the "L" key to advance the participant to the virtual CRT task scene.]

[(In the VR screen (GUI in VR), right after the store) click "Menu - Resetting standing position" to locate the participant towards the CRT workstation]

We will now load the first ADL task that you will train on, the Clothespin Relocation Task.

[Introduce CRT training requirements.]

The participant should complete the experiment while seated in a chair with nothing in front of them to limit upper-body movement. The chair's height should be adjusted at the beginning of the session before conducting the SteamVR room setup.

In this session, we will measure your mastery of handling, and the respective control mode, while completing the Clothespin Relocation Task (CRT).

For this task, you will move three clothespins from a middle horizontal bar on the clothespin base station to a vertical bar extending upward on the base station. You will begin the task with a movement of the right-most clothespin and, as quickly as possible, complete all pins.

Proceed to move the three clothespins as fast as possible (from horizontal to vertical + from vertical to horizontal). After successfully placing the sixth clothespin, we can start training sessions under timed mode.

If participants' performance is too bad, experimenters can change the threshold % for both sensors and make participants do additional untimed training to have consistent performance.

If you drop a clothespin, another clothespin will respawn on the table in front of you.

If you are ready, make your control mode open/close to pick up the pin whenever the training begins directly.

[Do countdown and run stopwatch to measure time to move three pins]

➢**DO NOT PRESS SPACEBAR** because that will pop up a task completion message exactly after 35 seconds, which was the training threshold for DC in Phase I. Instead, an experimenter needs to manually measure the time to move three pins using stopwatch (preferably in the phone).

[Training criterion for the CRT]
The experimenter will check the training criteria for each device mode: The training will be terminated if the participant successfully moves three clothespins within 00s for the PR control mode, **68s for the DC** control mode, and 00s for the CC control during three consecutive trials. If not, allow the participant additional training trials until the average of the last 3 trials falls within the criterion time range. Between each trial, allow the participant 1-2 min to rest.

[Upon training completion, press the "ESC" key to escape from the task scene and reload the main menu scene.]

[Add each training trial's information in the Google sheet – Pilot data]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

[Calculate the average of three sequential trials. See if it is shorter than 45 seconds. Then, participants can pass the training. If not, participants need to do training again.]

[Between the training sessions, participants can rest 1-minute]

[SHAP]

[Select the SHAP task and appropriate setting for the next session. Load the VR menu scene.]

[Press the "L" key to advance the participant to the virtual SHAP task scene.]

We will now load the second ADL task you train on, the SHAP or Door Handle Task.

[Introduce SHAP training requirements.]

The participant should complete the experiment while sitting in a chair with nothing in front of them to limit upper-body movement. The chair's height should be adjusted at the beginning of the session before conducting the SteamVR room setup.

In this session, we will measure your mastery of device handling, and the respective control mode, while completing the Southampton Hand Assessment Procedure, or SHAP.

For this task, you will rotate the door handle using a power grip until it is fully open. This action will be followed by a return of the handle to the original position and then a release of the handle.

*For a rotation to be successful, the handle must rotate clockwise a minimum of 90° and then return to 0° before being released. You can do this until you feel comfortable, **at least** five trials.*

(SHAP official website: http://www.shap.ecs.soton.ac.uk/about-usage.php?task=door)

If you are ready, make your control mode open/close to directly grab the door handle whenever the training begins.

[After the countdown, press "spacebar"]

[A training criterion for SHAP]
The participant should perform the task at a self-selected speed and be allowed to practice the required movements until satisfactory performance is achieved (Montagnani et al., 2015).

[Add each trial's time information in the Google sheet]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

[Upon training completion, press the "ESC" key to escape from the task scene and reload the VR menu scene.]

5. Test session

a. CRT

➢**DO NOT FORGET** to use a video recorder to capture both **Unity** screen and participants' **hand gestures** together. **DO NOT** capture participants face.

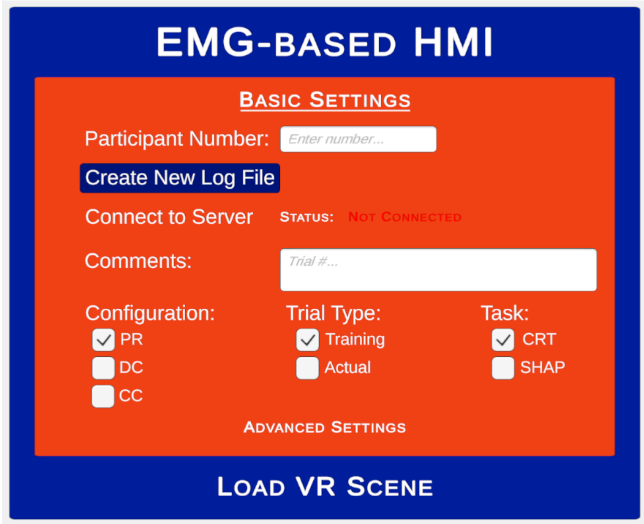
➢**DO NOT TALK or ENCOURAGE participants during the actual trials**

Now you will begin an actual test trial. In the CRT, there are 3 trials. Each trial takes 2 minutes. Between each trial, there is a 2-minute rest in which you will remove the VR headset. After the rest, you will be required to recalibrate the eye-tracking system.

During the task, you must move as many clothespins as possible from the horizontal rod to the vertical rod and back within the 2-min timed trial. After the time has expired, a TASK COMPLETE message will appear on the HUD.

I will give you the command to start the test trial when you are ready.

[Select the CRT task and appropriate settings for the next session. Select "Actual" for the trial type. Load the VR menu scene and instruct the participant to don the headset.]



[Make sure to give participants 2-min rest time before they start]

[Experimental Trial 1]

[Press the "L" key to advance the participant to the virtual CRT task scene.]

If you are ready, make your control mode open/close to directly pick up the pin whenever the training begins.

[When the participant indicates they are ready, say "Three, two, one, Start" and press "spacebar" to begin the task timer.]

[Manually count the number of pins moved with a pen and note]

[When the participant finishes the task, press the "ESC" key to escape from the task scene and reload the VR menu scene.]

[Add the performance in the Google sheet – Pilot data]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

Now that this test trial is complete, we ask that you fill out this questionnaire, which will help us understand the amount of workload that you experienced while using the virtual prosthetic device in the specific simulated ADL task.

[Ask the participant to fill out the SSQ form]

We now ask that you fill out a workload demand ranking form. This form is intended to help us understand what types of demands are most important to the performance of the ADL task that you just completed.

The form presents rating scales for the six workload demand components that you ranked at the close of your earlier training session. Each scale includes a line with anchors of

"Low" (0) and "High" (100). For each demand factor, please rate the level of workload that you felt while performing the ADL test with the virtual prosthetic device.

[Ask the participant to fill out the NASA-TLX form]

[Provide them with the NASA-TLX rating form]

Once the participants fill out two forms, they can rest for 2-minutes.

[Experimental Trial 2]

[Press the "L" key to advance the participant to the virtual CRT task scene.]

If you are ready, make your control mode open/close to directly pick up the pin whenever the training begins.

[When the participant indicates they are ready, say "Three, two, one, Start" and press "spacebar" to begin the task timer.]

[Manually count the number of pins moved with a pen and note]

[When the participant finishes the task, press the "ESC" key to escape from the task scene and reload the VR menu scene.]

[Add the performance in the Google sheet – Pilot data]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

[Ask the participant to fill out the NASA-TLX and SSQ forms]

Once the participants fill out two forms, they can rest for 2-minutes.

[Experimental Trial 3]

[Press the "L" key to advance the participant to the virtual CRT task scene.]

If you are ready, make your control mode open/close to directly pick up the pin whenever the training begins.

[When the participant indicates they are ready, say "Three, two, one, Start" and press "spacebar" to begin the task timer.]

[Manually count the number of pins moved with a pen and note]

[When the participant finishes the task, press the "ESC" key to escape from the task scene and reload the VR menu scene.]

[Add the performance in the Google sheet – Pilot data]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

[Ask the participant to fill out the NASA-TLX and SSQ forms]

Once the participants fill out two forms, they can rest for 2-minutes.

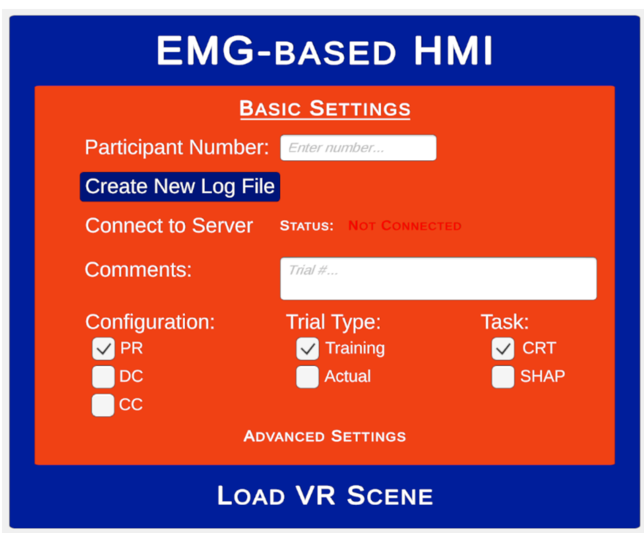
b. SHAP Test

Now, you will begin an actual test trial. In the SHAP task, there are 3 trials. Each trial includes five timed task executions. Between each trial, there is a 2-minute rest in which you will remove the VR headset. After the rest, we will recalibrate the eye-tracking system if necessary.

At the beginning of each trial, you will rotate the door handle using a power grip until it is fully open. You will then return the handle to its original position as quickly as possible. After 5 successful repetitions of this task, a TASK COMPLETE message will appear on the HUD.

I will give you the command to start the test trial when you are ready.

[Select the SHAP task and appropriate settings for the next session. Select "Actual" for the trial type. Load the VR menu scene and instruct the participant to don the headset.]



You may now place the VR headset back on your head.

[Experimental Trial 1]

[Press the "L" key to advance the participant to the virtual SHAP task scene.]

[When the participant indicates they are ready, say "Start."]

[Using stopwatch, manually measure the time to rotate door handle five times]

[When the participant finishes the task, press the "ESC" key to escape from the task scene and reload the VR menu scene.]

[Add the performance in the Google sheet – Pilot data]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

[Ask the participant to fill out the NASA-TLX and SSQ forms]

Once the participants fill out two forms, they can rest for 2-minutes.

[Experimental Trial 2]

[Press the "L" key to advance the participant to the virtual SHAP task scene.]

[When the participant indicates they are ready, say "Start."]

[Using stopwatch, manually measure the time to rotate door handle five times]

[When the participant finishes the task, press the "ESC" key to escape from the task scene and reload the VR menu scene.]

[Add the performance in the Google sheet – Pilot data]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

[Ask the participant to fill out the NASA-TLX and SSQ forms]

Once the participants fill out two forms, they can rest for 2-minutes.

[Experimental Trial 3]

[Press the "L" key to advance the participant to the virtual SHAP task scene.]

[When the participant indicates they are ready, say "Start".]

[Using stopwatch, manually measure the time to rotate door handle five times]

[When the participant finishes the task, press the "ESC" key to escape from the task scene and reload the VR menu scene.]

[Add the performance in the Google sheet – Pilot data]
TAMU: Actual-TAMU tab
UF: Actual-UF tab

[Ask the participant to fill out the NASA-TLX and SSQ forms]

Once the participants fill out two forms, they can rest for 2-minutes.

[Baseline pupil size - after the last actual trial]

➢**Before measuring "Baseline pupil size – after the last trial", make participants take of the headset and get rest for 2 minutes to stress out their pupils**

[Perform pupil size collection procedure again to capture post-task pupil diameter. Follow the same procedure in "before the first actual trial"]

[Press the "ESC" key to end the session and reload the VR program to the main menu.]

[Stop recording OBS (1 hr = 1 gb)**]**

➢**End the video recording**.

6. Debrief

a. Usability evaluation form

[Hand the participant the usability forms (USE and QUEST 2.0) and a pen.]

These questionnaires are intended to assess the usability of the virtual prosthetic device that you used during the experiment. Please answer the questions in the form. Let me know if you have any questions.

b. Payment form

[Hand the participant a Payment Form and a pen.]

Now that all aspects of the experiment are complete, we ask that you please fill out this payment form. You will be paid $15 per hour for your participation.

[Copy the payment form for Lab records.]

[Inform the participant that payment for the experiment can be immediately received as an Amazon gift card.]

c. Copy of the consent form

[Prepare a copy of the consent form.]

The data collected today will be used to study cognitive workload in using different EMG sensor-based Virtual Human-Machine Interfaces (HMIs). If you are interested in future information about this study or have any questions, please contact Dr. Zahabi. Her contact information is listed in the consent form that you will take home today.

[Give the participant a copy of the consent form and an amazon gift card.]

Thank you for participating in this study.

7. Usability evaluation forms (This will be provided to participants)

➢ **Ensure that participants evaluate the usability of EMG+VR interface compared to the situation that they imagine themselves as amputee patients doing CRT and SHAP without a prosthetic device.**

a. USE (Usefulness, satisfaction, and Ease of use)

- Please rate your agreement with these statements.
  - Try to respond to all the items.
  - For items that are not applicable, use: NA
- Please respond to the following question about the virtual prosthetic device you used in this experiment.
- Optionally provide comments and your email address in the box:

USEFULNESS		1	2	3	4	5	6	7		N/A
1. It helps me be more effective.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
2. It helps me be more productive.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
3. It is useful.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
4. It gives me more control over the activities in my life.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
5. It makes the things I want to accomplish easier to get done.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
6. It saves me time when I use it.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
7. It meets my needs.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
8. It does everything I would expect it to do.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
EASE OF USE	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
9. It is easy to use.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
10. It is simple to use.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
11. It is user friendly.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
12. It requires the fewest steps possible to accomplish what I want to do with it.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
13. It is flexible.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
14. Using it is effortless.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
15. I can use it without written instructions.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	

16. I don't notice any inconsistencies as I use it.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
17. Both occasional and regular users would like it.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
18. I can recover from mistakes quickly and easily.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
19. I can use it successfully every time.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
EASE OF LEARNING	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
20. I learned to use it quickly.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
21. I easily remember how to use it.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
22. It is easy to learn to use it.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
23. I quickly became skillful with it.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
SATISFACTION	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
24. I am satisfied with it.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
25. I would recommend it to a friend.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
26. It is fun to use.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
27. It works the way I want it to work.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
28. It is wonderful.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
29. I feel I need to have it.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	
30. It is pleasant to use.	Strongly disagree	O	O	O	O	O	O	O	Strongly agree	

- List the most negative aspect(s):
  - 1.
  - 2.
  - 3.
- List the most positive aspect(s):
  - 1.
  - 2.

- 3.

b. QUEST 2.0

Quebec User Evaluation of Satisfaction with assistive Technology

Participant number: __________

Device configuration (select one): _DC/ PR/ CC_

Date : ______________

The purpose of the **QUEST** questionnaire is to evaluate how satisfied you are with your assistive device. The questionnaire consists of 8 satisfaction items.

- For each of the 8 items, rate your satisfaction with your assistive device by using the following scale of 1 to 5.

1	**2**	**3**	**4**	**5**
not satisfied at all	not very satisfied	more or less satisfied	quite satisfied	very satisfied

- Please circle or mark the **one number** that best describes your degree of satisfaction with each of the 8 items.
- **Do not** leave any question unanswered.
- For any item that you were not "very satisfied", please comment in the section ***comments***.

Thank you for completing the QUEST questionnaire.

1	2	3	4	5
not satisfied at all	not very satisfied	more or less satisfied	quite satisfied	very satisfied

ASSISTIVE DEVICE ***How satisfied are you with,***	
1. the **dimensions** (size, height, length, width) of your assistive device? *Comments*:	1 2 3 4 5
2. the **weight** of your assistive device? *Comments*:	1 2 3 4 5
3. the **ease in adjusting** (fixing, fastening) the parts of your assistive device? *Comments*:	1 2 3 4 5
4. how **safe and secure** your assistive device is? *Comments*:	1 2 3 4 5
5. the **durability** (endurance, resistance to wear) of your assistive device? *Comments*:	1 2 3 4 5
6. how **easy** it is to use your assistive device? *Comments*:	1 2 3 4 5
7. how **comfortable** your assistive device is? *Comments*:	1 2 3 4 5
8. how **effective** your assistive device is (the degree to which your device meets your needs)? *Comments*:	1 2 3 4 5

1	2	3	4	5
not satisfied at all	not very satisfied	more or less satisfied	quite satisfied	very satisfied

- Below is the list of the same 8 satisfaction items. PLEASE **SELECT THE THREE ITEMS** that you consider to be **the most important to you**. Please put an X in the **3 boxes** of your choice.

☐ 1. Dimensions

☐ 2. Weight

☐ 3. Adjustments

☐ 4. Safety

☐ 5. Durability

☐ 6. Easy to use

☐ 7. Comfort

☐ 8. Effectivenss