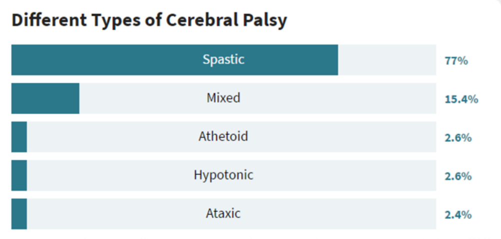
NEUROMOTUS: A NOVEL INTENT-BASED MOVEMENT PREDICTION SYSTEM THAT OPTIMIZES EXOSKELETONS TO ENHANCE MOBILITY FOR CEREBRAL PALSY PATIENTS

Ishan Ahluwalia

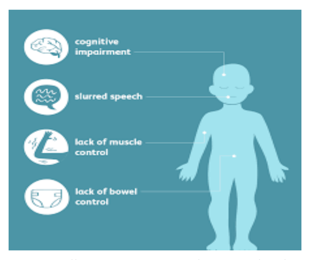
Project ID: EB0043

INTRODUCTION: CEREBRAL PALSY

Cerebral palsy (CP) is a group of movement based disorders that primarily appears in childhood. It is caused by abnormal brain development or brain damage that affects the body's mobility, posture, and balance.



Source: https://www.verywellhealth.com/cerebral-palsy-symptoms-and-complications-4160369



Spastic cerebral palsy is the most common type. Most individuals with spastic CP experience high muscle tone and exaggerated, jerky movements.

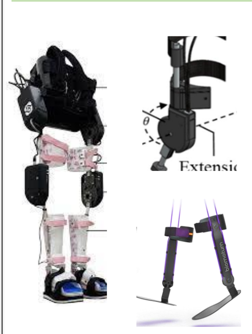
About 1M people in the US have at least one symptom of cerebral palsy. More than 10,000 babies are born each year with CP, and 1500 school-aged kids are diagnosed each year.

EXOSKELETONS FOR CP PATIENTS

Exoskeletons are wearable devices that provide external support to the body and can assist with movement. For individuals with cerebral palsy (CP), exoskeletons have the potential to offer several benefits:

1. Improved mobility 2. Increased independence 3. Improved quality of life

EXOSKELETON DESIGN

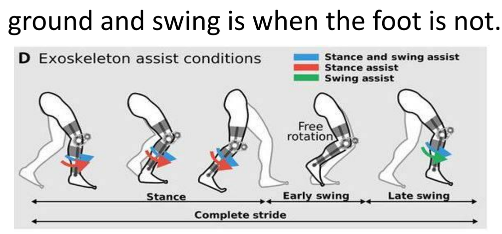


Knee Actuator: Provides rotational torque to the knee joint

Ankle Actuator: Provides rotational torque to the ankle joint

EXOSKELETON ASSISTANCE

These actuators are initiated on a stance and swing basis. Stance refers to the time when the foot is in contact with the ground and swing is when the foot is not.



Source: https://www.cbinsights.com/research/robotic-exoskeleton-cerebral-palsy-walk-upright/

CHALLENGES WITH CURRENT EXOSKELETONS FOR CP PATIENTS

Current exoskeletons for CP use a one size fits all method, where they are based on a basic walking movement in a straight line. This means when a Cerebral Palsy patient wants to climb stairs, sit down, or jump, the current exoskeletons are rendered powerless.

	Cerebral Palsy Exoskeleton Challenges
P-REX (2019)	Specific to walking forward. Assistive powers lend powerless when performing the abundance of other movements.
NIH (2020)	Meant for rudimentary walking pattern: straight and turn. Leaves out the numerous other movements humans need to perform
ReWalk (2016)	IMU's capabilities are limited to a binary classification of walking or not, leaving out a number of walking patterns

EXPERT OPINIONS ON CHALLENGES OF CURRENT EXOSKELETONS

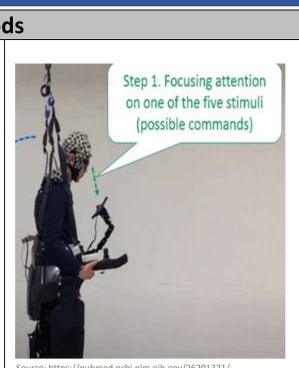
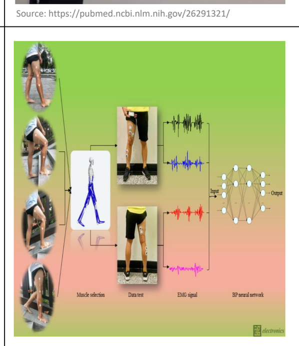
"When people wore exoskeletons while performing tasks that required them to think about their actions, their brains worked overtime and their bodies competed with the exoskeletons"

"Existing exoskeletons for CP patients have failed to make the step into the real world because they need to be fine-tuned to a person's gait over long periods"

PROBLEM STATEMENT

HOW TO OPTIMIZE EXOSKELETONS TO ENABLE ESSENTIAL MOVEMENTS FOR CP PATIENTS

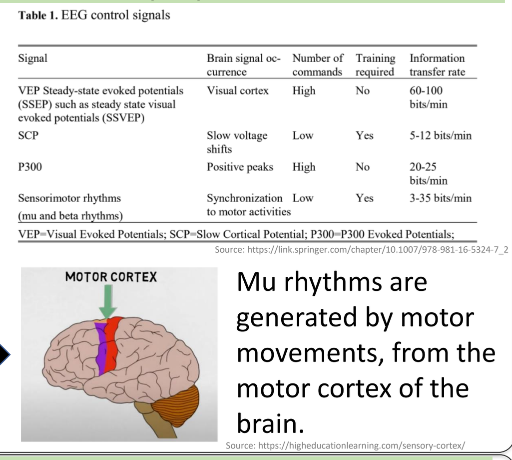
CURRENT SOLUTIONS

Methods		Challenge
Steady State Visual Evoked Potentials is a cutting-edge technique that utilizes visual cues, such as flashing lights, to elicit potentials that are highly correlated with specific movements of individual users.		This solution predicts user movement effectively, but has drawbacks including asynchronous operation, high costs, and limited practicality due to the need for the patient to focus on a visual cue for 2-3 seconds to trigger a specific movement.
Surface electromyography (sEMG): Electrical signals from muscles - is one way to estimate human intent. sEMG contains anticipatory information that precedes the associated limb movement.		Although this method is effective for some people, it is not suitable for individuals with Cerebral Palsy due to the impact of mixed signals on their spastic muscles, making EMG data unusable for them.

NEW INTENT BASED APPROACH

BRAIN COMPUTER INTERFACE (BCI)

EEG signals are recordings of brain activity and provide insights into brain function. Different types of EEG signals include:



Alpha Waves (8-12 Hz relaxation)
Beta Waves (12-30 Hz mental activity)
Gamma Waves (30-100 Hz cognitive proc)
Theta Waves (4-8 Hz sleep and daydreams)
Delta Waves (< 4 Hz deep sleep)
Mu Rhythms (7-14 Hz motor processes)
P300 (0.5-4 Hz cognitive processing)

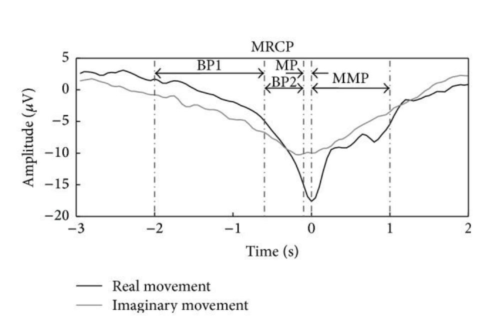
Mu rhythms are generated by motor movements, from the motor cortex of the brain.

BEREITSCHAFTSPOTENTIAL (BP)

MRCP or movement related cortical potentials refers to the voltage of brain activity during human based motor tasks.

The EEG data of the 2 second period before movement starts is known as **bereitschaftspotential (BP)** or intent

1. Early BP: slow downset of voltage around 1.5 seconds before performing an action
1. Late BP: Fast downset of voltage 0.5 seconds before voluntary action



CAN MOVEMENT INTENT BE DETECTED FOR CP PATIENTS?

Despite the motor limitations of Cerebral Palsy patients, most of the time the brain activity with respect to intent remains intact.

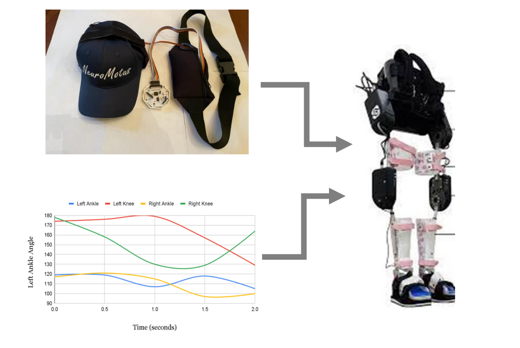
Studies have determined that the intent signals of most Cerebral Palsy Patients are comparable to that of non-CP patients.

SOLUTION OVERVIEW

CURRENT SOLUTION

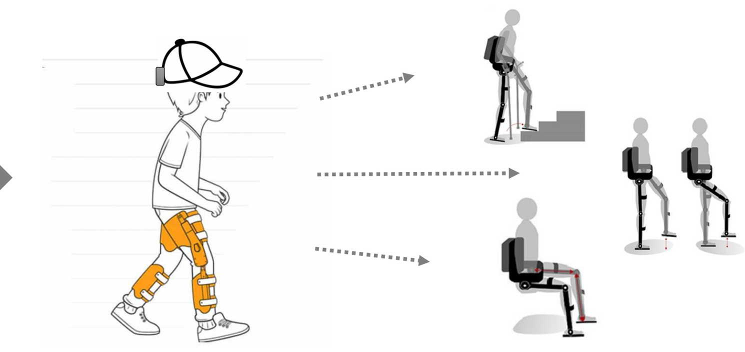
Currently Cerebral Palsy patients have severe challenges with mobility due to muscle spasticity

TECHNOLOGY: BCI + EXOSKELETON



The NueroMotus system uses a Brain-Computer Interface to anticipate user movements by detecting intention. The intent data, along with angle visualization, is transmitted to an exoskeleton to facilitate execution of the intended movement

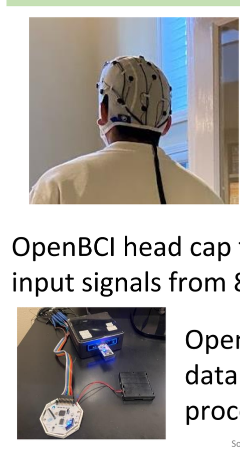
BETTER LIFE FOR CP PATIENTS



This project broadens the scope of movement available for Cerebral Palsy patients and provides CP exoskeletons with a system to expand their use case beyond clinical settings

PHASE 1: MOVEMENT PREDICTION FOR LEG RAISE

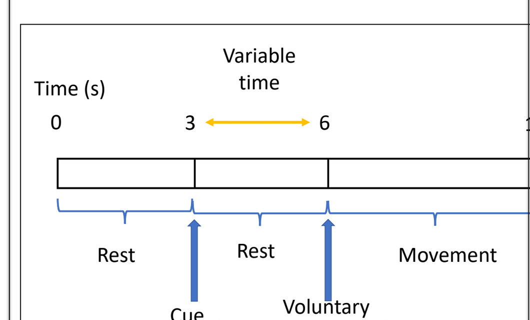
HARDWARE SETUP



OpenBCI head cap for EEG data. Maximized input signals from 8 EEG electrode channels.

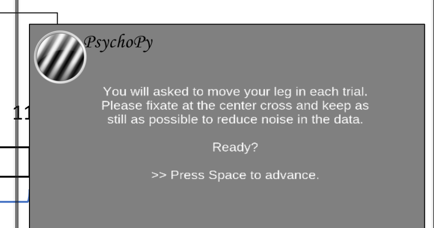
Open BCI Cyton board for data collection, Intel NUC for processing.

EXPERIMENT DESIGN



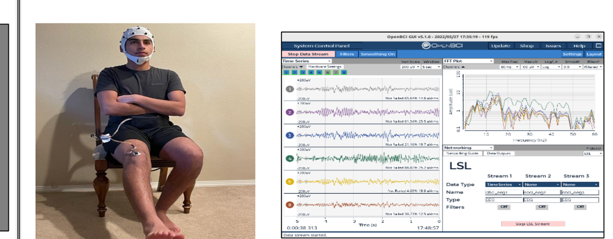
The timing and experimental procedure for the leg raise test can be seen above.

PSYCHOPY



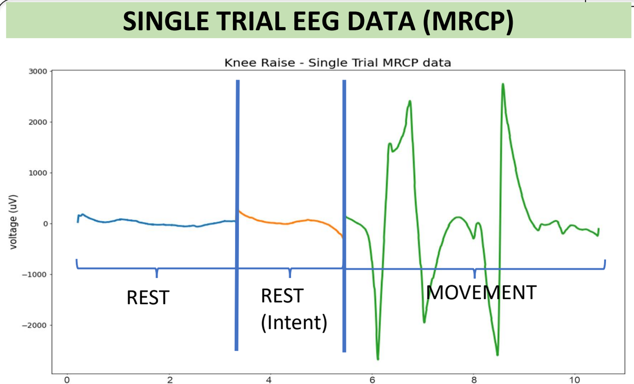
Experiment design is implemented into a time synchronous software (PsychoPy).

DATA COLLECTION



Following the protocol given from PhyscoPy, the experiment is conducted multiple times. EEG data is collected for 50 trials.

SINGLE TRIAL EEG DATA (MRCP)



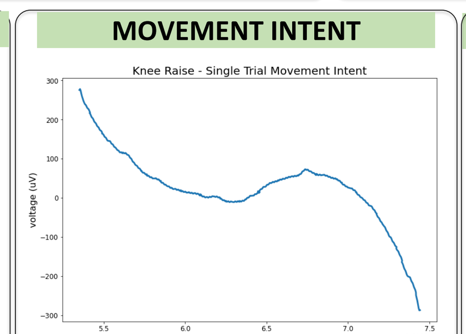
MRCP data collected with intent markers based on EMG data.

ISOLATING INTENT

MyoWare sensor

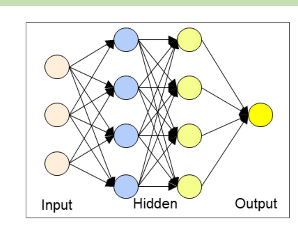
EMG data was used to detect when voluntary movement began. Furthermore, using this information, the 2 second time period of intent prior to movement was isolated.

MOVEMENT INTENT



Isolated BP/Intent data, shows a distinct drop in voltage, indicating movement intent.

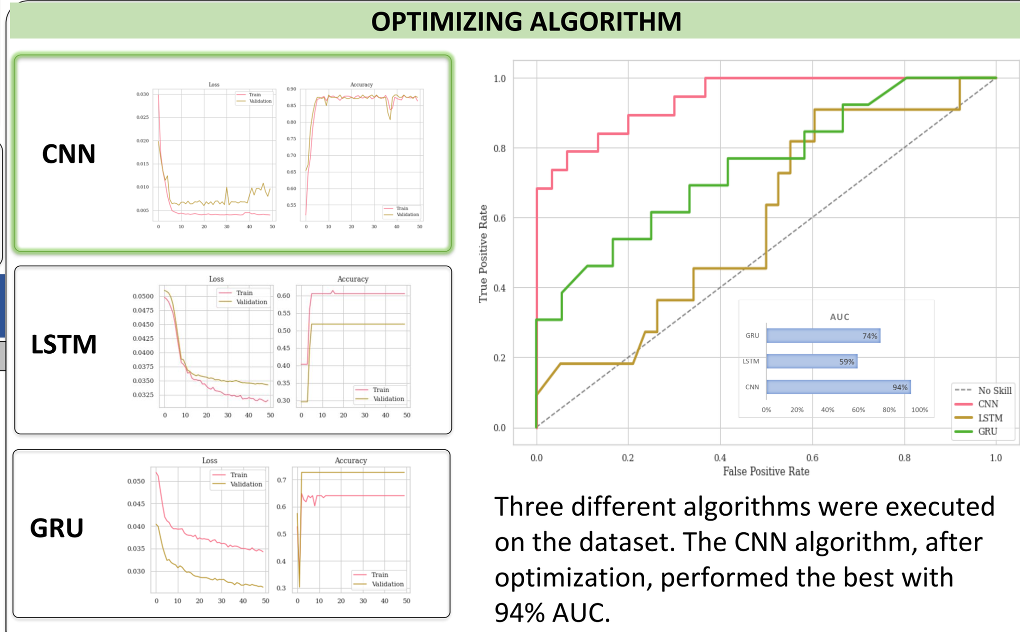
BINARY CLASSIFIER



Using this dataset, a CNN based binary classifier was trained. The classifier was able to detect 'rest' vs 'leg raise' intent with 94% accuracy.

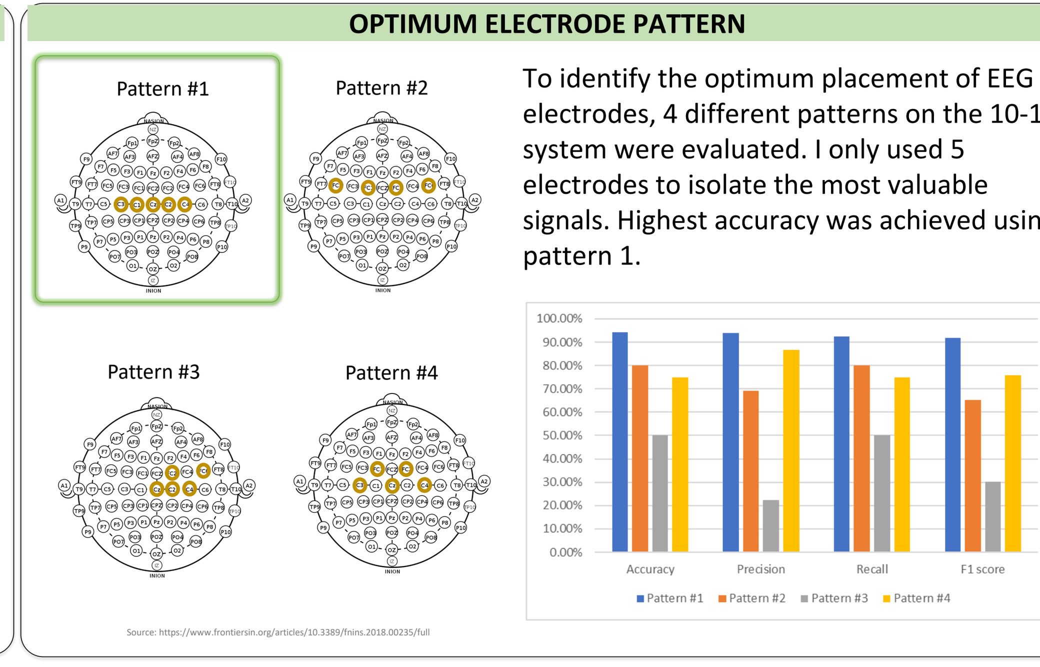
Optimizing Electrode placement and algorithm

OPTIMIZING ALGORITHM



Three different algorithms were executed on the dataset. The CNN algorithm, after optimization, performed the best with 94% AUC.

OPTIMUM ELECTRODE PATTERN

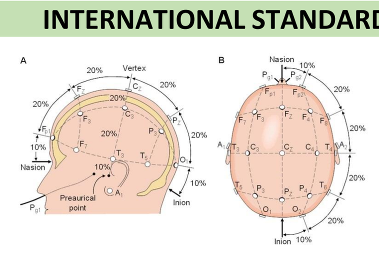


To identify the optimum placement of EEG electrodes, 4 different patterns on the 10-10 system were evaluated. I only used 5 electrodes to isolate the most valuable signals. Highest accuracy was achieved using pattern 1.

PHASE 2: PREDICTING MULTIPLE MOVEMENTS

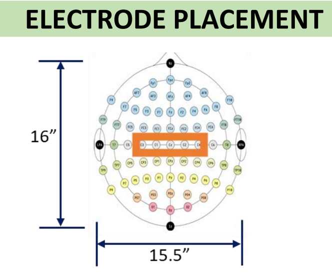
DEVELOPING THE NEUROMOTUS CAP

INTERNATIONAL STANDARD



10-10 and 10-20 EEG electrode placement caps were used in this project.

ELECTRODE PLACEMENT



Measurement of Nasion-to-Inion and Preaurical left and right points were done for exact electrode placement.

INSTALLING DRY ELECTRODS

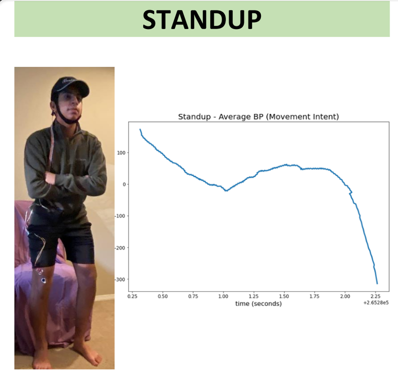
Based on consistent cap placement dry portable electrodes were placed at CZ, C1, C3, C2, C4 for isolating motor cortex data.

NEUROMOTUS CAP

Final product was connected to Cyton board. Ear clip electrode was used for reference ground.

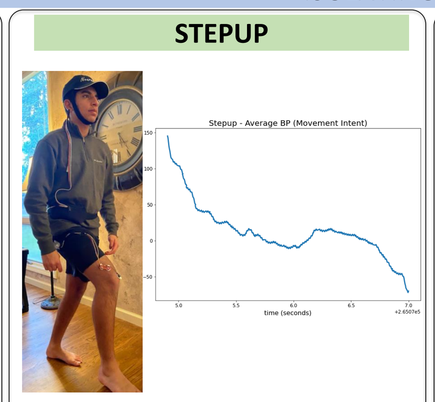
ISOLATING INTENT DATA FOR MULTIPLE MOVEMENTS

STANDUP



Average of isolated intent/BP data for Standup trials

STEPUP

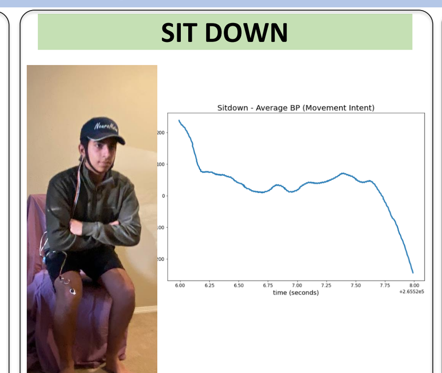


Average of isolated intent/BP data for Step-up trials

FORWARD WALK

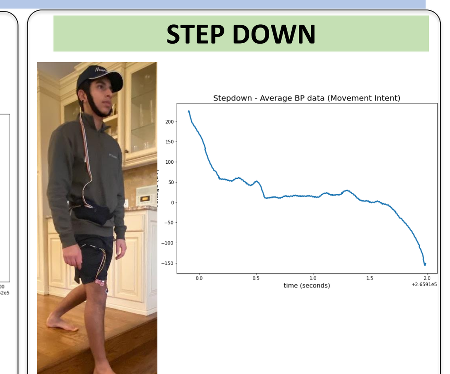
Average of isolated intent/BP data for Walk trials

SIT DOWN



Average of isolated intent/BP data for Sit-down trials

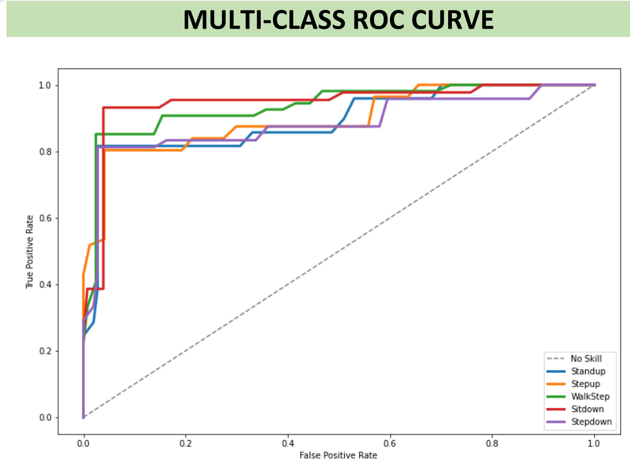
STEP DOWN



Average of isolated intent/BP data for Stepdown trials

RESULTS

MULTI-CLASS ROC CURVE



CONFUSION MATRIX

PERFORMANCE NUMBERS

	Precision	Recall	F1-score	support
Rest	1.00	1.00	1.00	196
Standup	0.85	0.82	0.83	196
Stepup	0.82	0.80	0.81	224
Walkstep	0.88	0.85	0.87	216
Sitdown	0.80	0.93	0.86	176
Stepdown	0.85	0.81	0.83	192
Accuracy			**0.87**	1200
Macro Avg.	0.87	0.87	0.87	1200

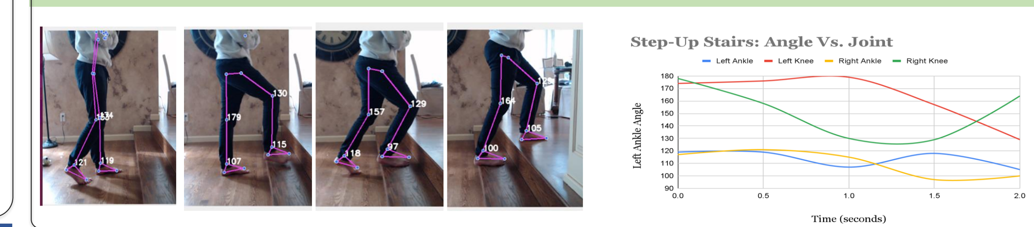
PHASE 3: MOTION ANGLE DATA

PURPOSE

Current exoskeleton's function using input torque. Torque is rotational force that is defined by the cross product of force and radius. This means that angles play a crucial factor in determining the input torques for CP exoskeletons. This angle visualization of essential movements will make the addition of such movements into exoskeletons seamless.

For each of the movements the NueroMotus system determines an angle pattern mapped for the **left** and **right knee** and **ankle** using a joint visualization software.

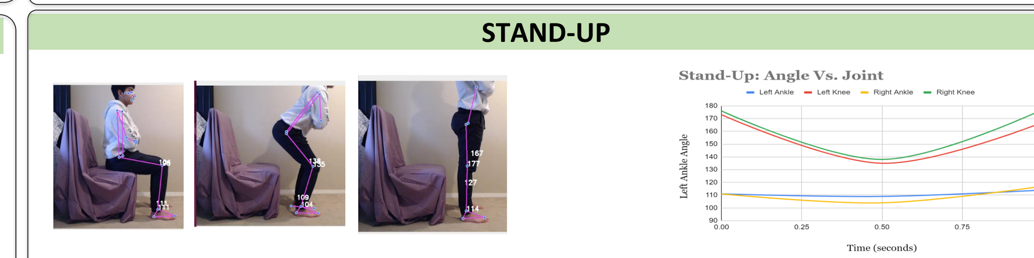
STEP-UP STAIRS



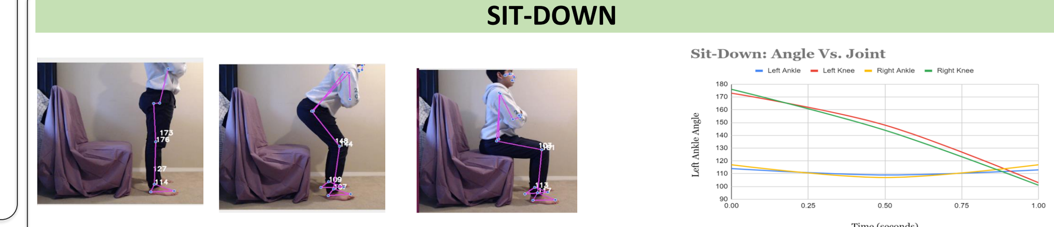
STEP-DOWN STAIRS

STEP FORWARD

STAND-UP

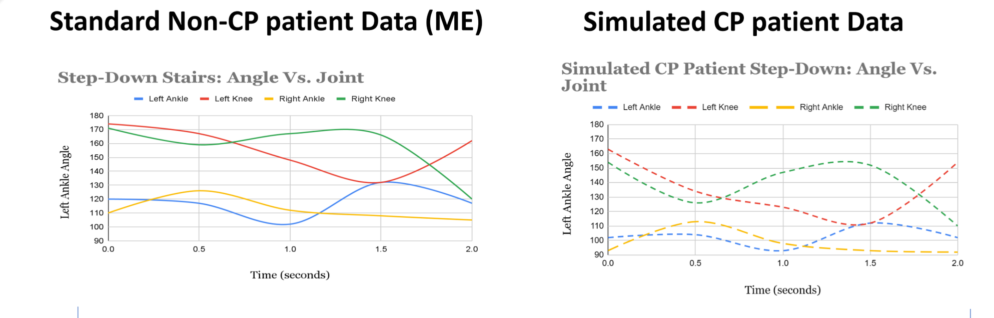


SIT-DOWN



INPUTS FOR EXOSKELETONS

Standard Non-CP patient Data (ME) **Simulated CP patient Data**



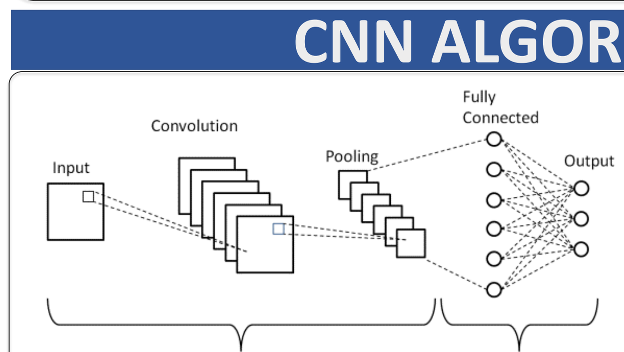
Angle Delta: Inputted as the rotational torque angle needed for a CP patient to perform the action

Direction Change Timepoints: Signifies when and how long rotational torque must be applied and what times directional torque needs to change

BIOMOTUM EXOSKELETON

Biomotum the exoskeleton company I am currently interning at requires these two inputs for the left and right ankles and knees to provide the CP patient with assistive powers. So, this angle visualization provides a means to gather that information effectively for the implementation of a vast number of additional movements.

CNN ALGORITHM



CNN is commonly used as an excellent image classifier, and I think that each EEG sample can be viewed as a one-dimensional image consisting of 5 color channels of voltage pixels along a time scale.

I used a CNN2D model with 4 convolution layers, each following a pooling layer, dropout layer, and batch normalization layer to avoid overfitting. Each convolutional layer included padding (5, 0) to maintain the output size as well as a stride of (1, 1). It convoluted across time, with each filter having a depth of 5, one for each channel of the EEG data. At the end of the CNN, it only had one affine layer followed by a softmax classifier. Lastly, adam optimizer as used with training over 50 epochs.

CONCLUSION

The NeuroMotus project has revolutionized the use of exoskeletons for Cerebral Palsy patients by developing a sophisticated closed-loop system. With an accuracy rate of 87%, this system predicts six essential daily movements. Moreover, an angle visualizing software has been used to precisely calculate assistive torque input times for each movement. The result is a groundbreaking advancement in assistive technology that greatly expands the applicability of exoskeletons for Cerebral Palsy patients.

IMPROVEMENTS

- Expands the range of mobility of CP exoskeletons to include 5 new and essential movements
- Provides a complete method to implement CP exoskeletons into real world settings
- Creates a harmonious relationship between the brain and exoskeleton
- Induces neuroplasticity for improved movement without mechanical aid

FUTURE WORK

1. Integrate NeuroMotus into Biomotum's Spark exoskeleton.
2. Improve the algorithm accuracy will be key to achieving optimal results for patients.
3. Clinical trials with Cerebral Palsy patients will offer valuable insights and help fine-tune the system.
4. Broaden the scope of NeuroMotus beyond Cerebral Palsy patients