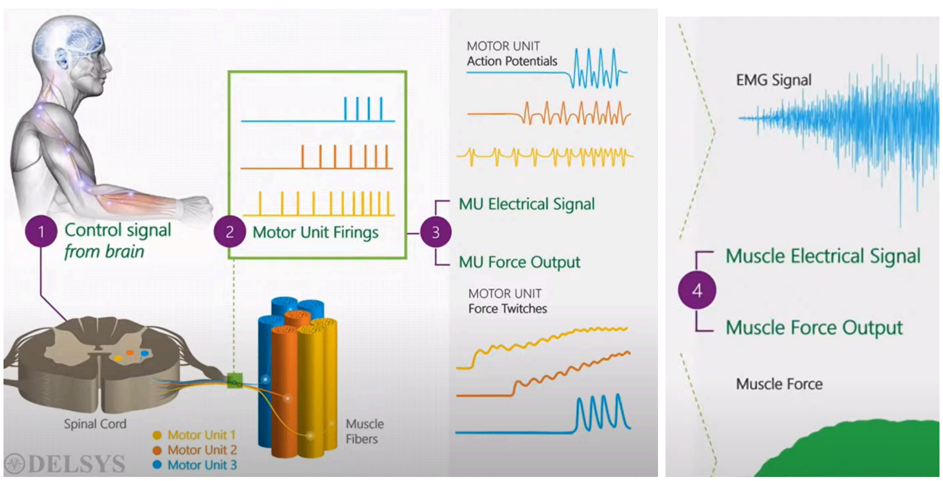
Science Fair Log Book

April 24, 2023

- *Started doing some research on what is muscle fatigue*

Electromyography (EMG): study of muscle function through the inquiry of the electrical signal the muscles emanate

- In sports biomechanics, it is a tool that provides access to physiological processes that are responsible for generating force and producing movement
    - And can help answer questions like “how can we improve running efficiency”, “athletes executing complex skills”, “designing and implementing training programs
- Associated with the contraction of muscles
  Origin:
    - Brain sends signals along the motor neurons which originate in the ventral horn of the spinal cord
    - Each signal innovates a group of muscles fibers called a motor unit
    - Motor unit: smallest controllable muscular unit we can measure



    - Contractions of motor units creates electrical signatures called motor unit action potentials (aka MU electrical signals)
        - Varying amplitudes of force that responds to motor units
        - First motor unit usually has the fastest firing and smallest unit
        - Last has slowest firing but is the largest

April 30, 2023

- *Watched video + took notes on how muscle fatigue is measured*

Measuring EMG data

- Intrinsic factors (cannot be controlled): fiber type, fiber diameter, motor unit firing rate, blood flow, conduction velocity, subcutaneous tissue, active motor units, motor points, lactic acid

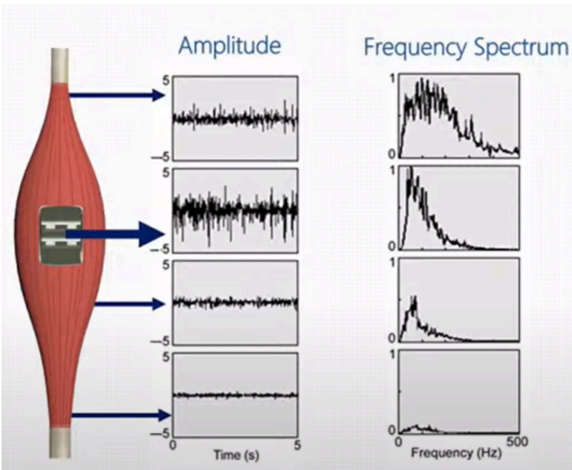
- Extrinsic factors (can be controlled): sensor location, sampling rate, skin impedance, signal resolution, sensor bandwidth, movement artifact, 50Hz/line noise, muscle crosstalk

May 10, 2023

- *Continued taking notes on how muscle fatigue is measured*
- *Looked more into sensor placement and the effectiveness/flaws of that*

Sensor Location

- Best location is on midline of the muscle far from tendon origins and innovation zones
    - Location of sensor/electrode affects amplitude and frequency spectrum of EMG signal

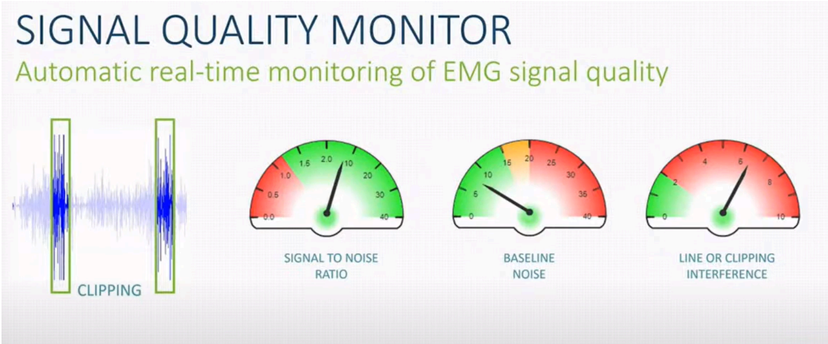


- Accurate sensor placement maximizes amplitude of EMG signal and minimizes muscle crosstalk from neighboring muscles
    - That's why we avoid edges of muscle

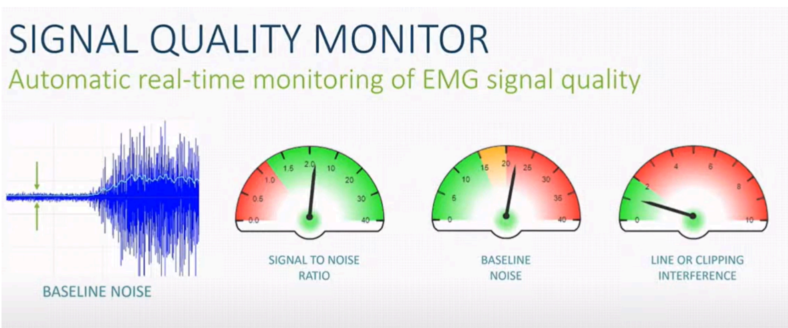
EMG signal quality monitor

- A number of noise sources can contaminate EMG signals
- Line interference from power lines/fluorescent lights represented by 50-60Hz originated from electromagnetic radiation
    - Can contaminate

- Detachment or excessive EMG signal amplitude can cause saturation of signal (aka clipping)
    - If this occurs, contact between sensor and skin should be secured and amplifier fain should be reduced OR location of sensor should be moved to reduce signal amplitude



- Baseline noise: composition of electronics noise from te EMG sensor and skin electrode interface
    - Placement and skin preparation assures a low baseline noise
        - Focus should be skin preparation → cleaning application site with alcohol wipe to remove excessive hair, dead skin sells and hydrate skin

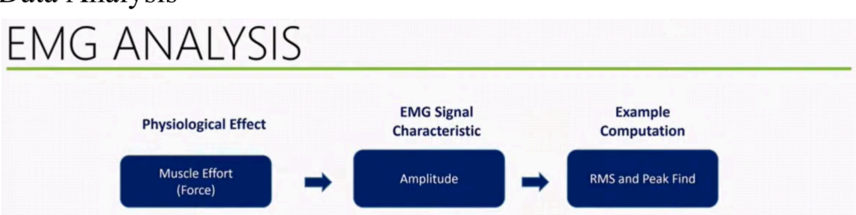


- Signal to noise ratio (SNR): indicates the ratio of EMG signal amplitude durin muscle contraction vs. unwanted electrical signal recorded when muscle is at rest (the baseline noise)
    - Measure of quality of energy signal
    - Higher SNR is more reliable with the discrimination of EMG data for underlying baseline

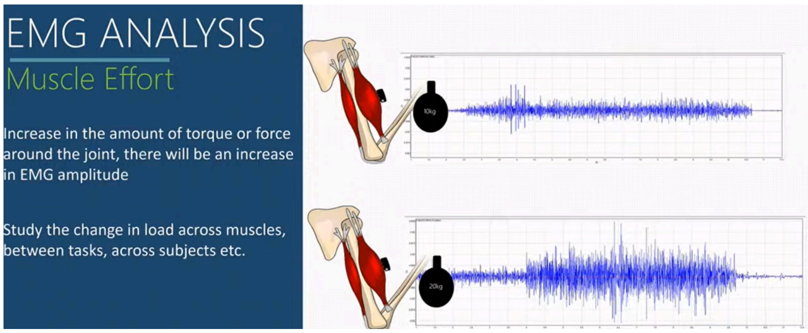
May 14, 2023

- *Tried analyzing an EMG signal whilst following a video of a persons nerve stimulation after holding a weight*
- *Learned about the correlation between heaviness of weight/ force exerted to hold the weight and the amplitude of the EMG signal*

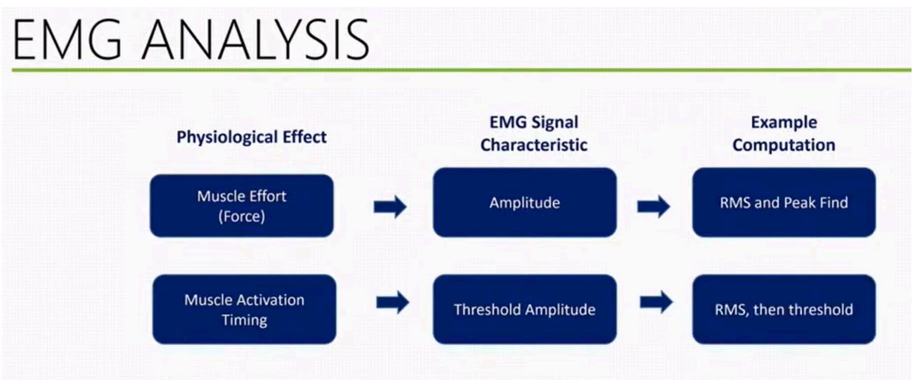
Data Analysis



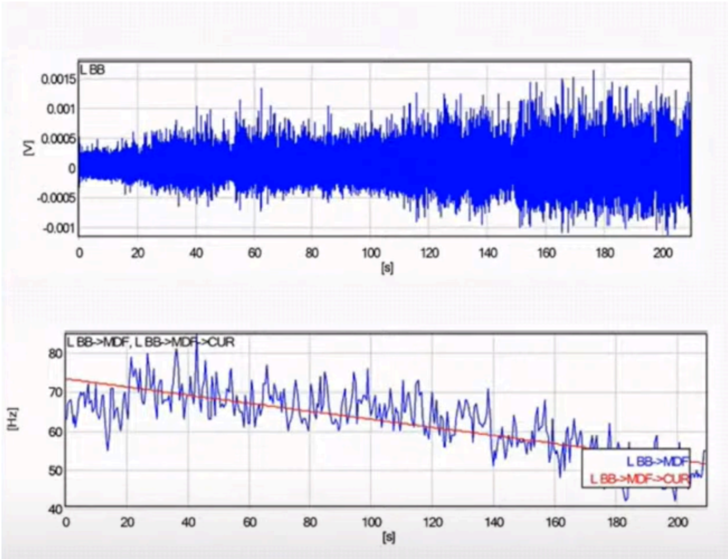
- Muscle effort: where user would desire to understand the physiological effects of how muscle(s) are working/how hard they are working
    - EMG signal is defined by its amplitude → can using a simpling moving average window filter such as root mean squared (RMS) and find peak to compute amplitude
        - As force/torque increases around joint, energy signal demonstrates sincrease in amplitude



- Heavier weight = greater force and amplitude



- Activation timing (aka on/off): common physiological effect studied where signal/amplitude goes beyond the threshold nad is judged on being on or off
    - Then filter EMG signal with eg. moving average window filter to do a threshold calculation based on number of standard deviations above the baseline noise level to determine if it is an on or off state



- 1st graph shows the raw EMG points
  - Shows increase in amplitude over time as the muscle is working harder to maintain the weight in this fixed join position
- 2nd graph shows the output after the signal has been processed with a median frequency calculation
  - Line of best fit shows decrease in frequency as contraction progressed through time

May 20, 2023

- *Started looking at previous studies done on similar topics*
  - *Something related to muscle fatigue while performing a fatiguing exercise either using weights or on an ergometer of some sort*

Analysis of EMG Measuremnts During Bicycle Pedalling
https://www.sciencedirect.com/science/article/abs/pii/0021929086901922

- Pedalling action of legs is caused by contraction of leg muscles
- Bicycles replacing transportation as we try to decrease the use of fossil fuels
- Active muscles identified in EMG measurements using a stationary exercise bicycle ergometer

The Neuromuscular Fatigue-Induced Loss of Muscle Force Control
https://pubmed.ncbi.nlm.nih.gov/36422953/

- Neuromuscular fatigue is the decreased production of maximal force caused by exercise which is affected by differing types of muscle contractions in fatiguing exercises.
  - Isometric contractions, dynamic concentric and eccentric contractions
- Capacity to generate maximum muscle for is not the only determinant of exercise performance
  - Ability to control submaximal forces also included

May 23, 2023

- *Read trusted scientific articles on the backgrounds of neuromuscular fatigue to familiarize myself in this topic*
- https://www.sciencedirect.com/topics/medicine-and-dentistry/muscle-isometric-contraction#:~:text=An%20isometric%20contraction%20is%20a,a%20fixed%20amount%20of%20weight
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3899915/#:~:text=There%20are%202%20types%20of%20isotonic%20contractions%3A%20concentric%20and%20eccentric.&text=In%20a%20concentric%20contraction%2C%20the,force%20the%20muscle%20is%20producing
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6969995/
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8997532/#:~:text=Central%20fatigue%20is%20defined%20as,processes%20are%20affected%20%5B18%5D
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6969995/
- https://iopscience.iop.org/article/10.1088/1757-899X/705/1/012010

May 24-25, 2023

- *Began to write an "introduction" with all the information from the previous sources on a background of neuromuscular fatigue*

Neuromuscular fatigue is defined as the decreased production of maximal force caused by exercise which is affected by differing types of muscle contractions in fatiguing exercises such as isometric contractions — muscle contraction without movement [ ] — or dynamic concentric and eccentric contractions characterized as flexion and extension of the muscle during exercise[ ]. An objective measure of neuromuscular fatigue is with the use of electromyography (EMG) which is through the inquiry of electrical signals the muscles emanate. This fatigue consists of two different types: peripheral and central fatigue. Peripheral fatigue is the cellular and mechanical changes in the muscular system and includes consequences like accumulation of lactic acid [ ] [ ] whereas central fatigue stems from the central nervous system as there is lack of motor drive due to neurochemical changes in the brain from prolonged exercise [ ]. A typical way to carry out these measurements is using a noninvasive method of applying an electrode in the midline of the muscle to measure currents generated during muscle contraction to represent neuromuscular activity. In some cases EMG signals may be contaminated by electromagnetic radiation, and excessive amplitude of EMG signal may cause saturation of the signal and thus the removal of those data points. Recently machine learning models have been adapted for measure of muscle fatigue — most typically in studies where participants were engaged in exercise related to the following muscles: rectus femoris, vastus lateralis, vastus medialis, semitendinosus, and biceps femoris [ ].

In previous studies machine learning has assisted in classification or detection of EMG threshold and amplitude in various forms of exercise like a stationary exercise bicycle ergometer or fatigue detection based on EMG signals using the three domains: time, frequency, and time-frequency [ ].

LSTM networks have been trained for classification of muscle fatigue according to patterns of EMG signals

June 1-5, 2023

- *Began to revise this and looked at a few more articles more in depth*

Neuromuscular fatigue is defined as the decreased production of maximal force caused by exercise which is affected by differing types of muscle contractions in fatiguing exercises such as isometric contractions — muscle contraction without movement [ ] — or dynamic concentric and eccentric contractions characterized as flexion and extension of the muscle during exercise[ ]. Research on this topic is crucial to

The neuromuscular system may become fatigued as a result of demanding high-intensity exercises because adenosine triphosphate (ATP) energy is depleted, lactic acid builds up, ion concentrations are disturbed, and neural transmission between the nervous system and muscles is hindered. This fatigue consists of two different types: peripheral and central fatigue. Peripheral fatigue is the cellular and mechanical changes in the muscular system and includes consequences like accumulation of lactic acid leading to decline in force/power performance [ ] [ ]. Central fatigue stems from the central nervous system as there is lack of motor drive due to neurochemical changes in the brain from prolonged exercise, thus reducing voluntary muscle activation and a decline in force/power output is also observed [ ][ ]. Voluntary activation refers to the ability of the central nervous system (CNS) to stimulate muscles despite experiencing fatigue, and is often assessed using the twitch interpolation technique. In this procedure, peripheral nerves are stimulated supramaximal during a maximal voluntary contraction (MVC), which, if muscle activation is submaximal, elicits a second, involuntary force known as a superimposed twitch. Following the maximal voluntary contraction (MVC), the amplitude of the superimposed twitch is quantified as a ratio relative to the potentiated twitch that immediately follows the MVC, and reductions in voluntary activation from pre- to post-exercise are commonly acknowledged as indicative of central fatigue [ ]. An objective measure of peripheral fatigue is with the use of electromyography (EMG). Typically, skeletal muscle fibers that are innervated by a motor neuron make up a motor unit — quantity of activated motor units affecting the intensity of muscle contraction. Most commonly for studies a surface EMG (sEMG) is used on participants — this noninvasive method of applying an electrode to the midline of the muscle detects the amount of electrical signals sent from the nervous system to actuate the muscle through alterations in frequency and amplitude [ ][ ]. The recorded single-channel EMG signal is an electrical activity that is superimposed with the total of the activations from various motor units and a variety of noise. While sEMG is easier to use than intramuscular EMG, sensor noise and muscle crosstalk is often picked up, thus needing the use of signal processing where high-pass filters are used to remove baseline drift or low-frequency noises.

June 9, 2023

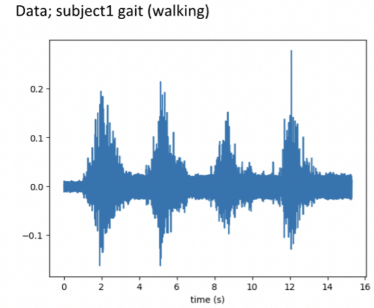
- *Realized that a major part of the information I had read up on/wrote about would most likely be irrelevant to my project*

- *Decided I wanted to purley focus on muscular fatigue rather than neuromuscular fatigue as I did not have enough knowledge to conduct research on the things related to the brain*
- *Began to shift my focus and look at studies in which data had already been taken so I could run machine learning tests on that instead*
- *Found this study done that had good data points: https://ieeexplore.ieee.org/document/9257909*
- *Another potential source: https://zenodo.org/records/5189275*

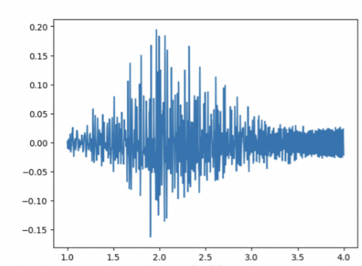
June 10, 2023

- *Looked at the papers more in depth*
- The paper #2 classifies 3 different activities (gait-walking, standing, sitting) of 14 subjects
- The activities are not intense for the person to be fatigue after 5-16seconds.
- Classification seems possible - just visualizing the spectrogram and signal for one person they look different.
- *Ran simple EMG signal on one individual:*

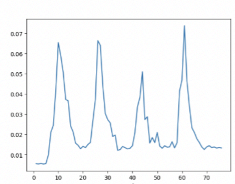
Data; subject1 gait (walking)



raw data@1kHz (16 seconds=16,000 samples)



first “pulse” (1-4seconds)



rms every 200 samples

June 14-16, 2023

- *Decided to go with the first study*
- *Read on a bit more of what the study was + wrote a summary/intro*

In this study a Myo-armband with 8 200Hz sEMG sesnors was worn on the muscle midline of the forearm by fifteen healthy young male adults. All participants were instructed to maintain a 90-degree flexion in their elbow while holding a 6-kilogram load with their right hand. Their forearms were positioned horizontally, with their palms facing upward during 120 seconds of recording isometric contraction until fatigue was reached [ ]. The three domains of time domain, frequency domain, and time-frequency domain can then be used to categorize the different types of EMG properties. Time domain filtering using root mean square (RMS) and mean absolute value (MAV) is used to remove unwanted noise and artifacts, and provides an overall magnitude of the signal with average signal amplitudes over a given time period that represents the level of muscle activation. The slope calculated is used to examine change in EMG amplitude over time

In the frequency domain, the shift in the EMG frequency spectrum toward lower frequencies is determined by the fast Fourier transform (FFT) approach. The most typical practice is to connect these measures to the original value or non-fatigue state mean and median power frequencies and to monitor the relative changes in the mean (MNF) and median power frequencies (MDF). Lastly time-frequency methodologies like a Short-Time Fourier Transform (STFT) is used to analyze frequency of muscle activity in short overlapping time windows [ ]. The peak force or amplitude of the EMG signal during the maximum voluntary contraction (MVC) task is extracted and used to calculate the MVC value. Statistical analysis is performed to summarize the data, and comparisons can be made between muscle groups, individuals, or conditions. A large determinant of muscular fatigue is the measurement of force and power output produced through the MVC. At a point of fatigue or past failure, MVC tests may begin to demonstrate a decline in force and power output in the form of electrical currents as recorded with surface electrodes [ ]. General trends of sEMG during MVC tests would show initial increase of signal amplitude due to muscle contraction under maximal effort representing force output, followed by a subsequent decline at a point of muscle fatigue or failure [ ].

June 20-July 18, 2023

- Ran a bunch of preliminary machine learning tests using root mean square methods to get slope
- Developed codes using the base of previous projects on google collab

The goal is to identify if the muscle shows fatigue and the strength of fatigue in prev. studies. Main result #1: As shown in the following figure for CHANNEL 7 using same PCA-spectrogram approach, the slope of the proposed method is higher in all cases, and for Individual #4 (starting from #0 in this plot) who shows a very small slope they are similar. It also improves the identification of individual #6, whose RMS is negative but we can see the fatigue state still moves farther from the cluster center.

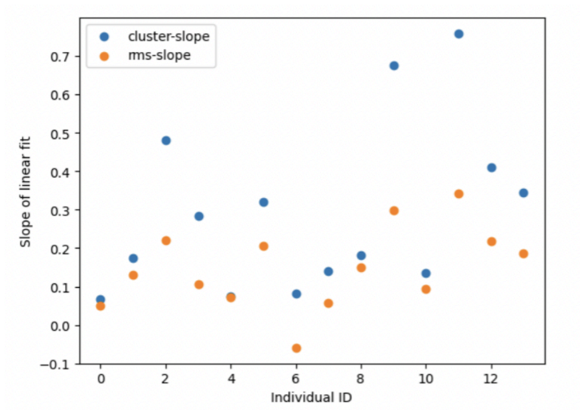


Figure 1-1: Slope of two measures (cluster distance) and (RMS) computed over the 120 seconds of each individual. Proposed cluster distance measure shows better detection performance, especially individual #6 where the RMS is “negative”, and slight improvement for #0 where rms slope is almost zero.

Main result #2: The onset of fatigue can be quantified.

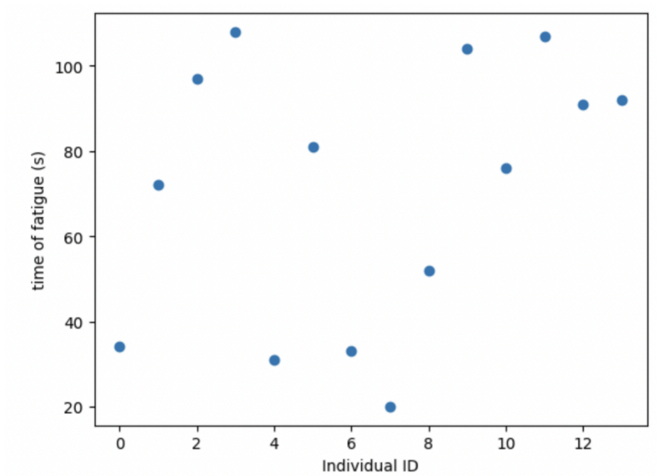


Figure 2-3: The estimated time of first fatigue using the 95 th percentile approach. This is per second since each spectrogram sample is corresponding to one second in time.

1. Supporting figures for Result #1 using the slope of the distance from cluster

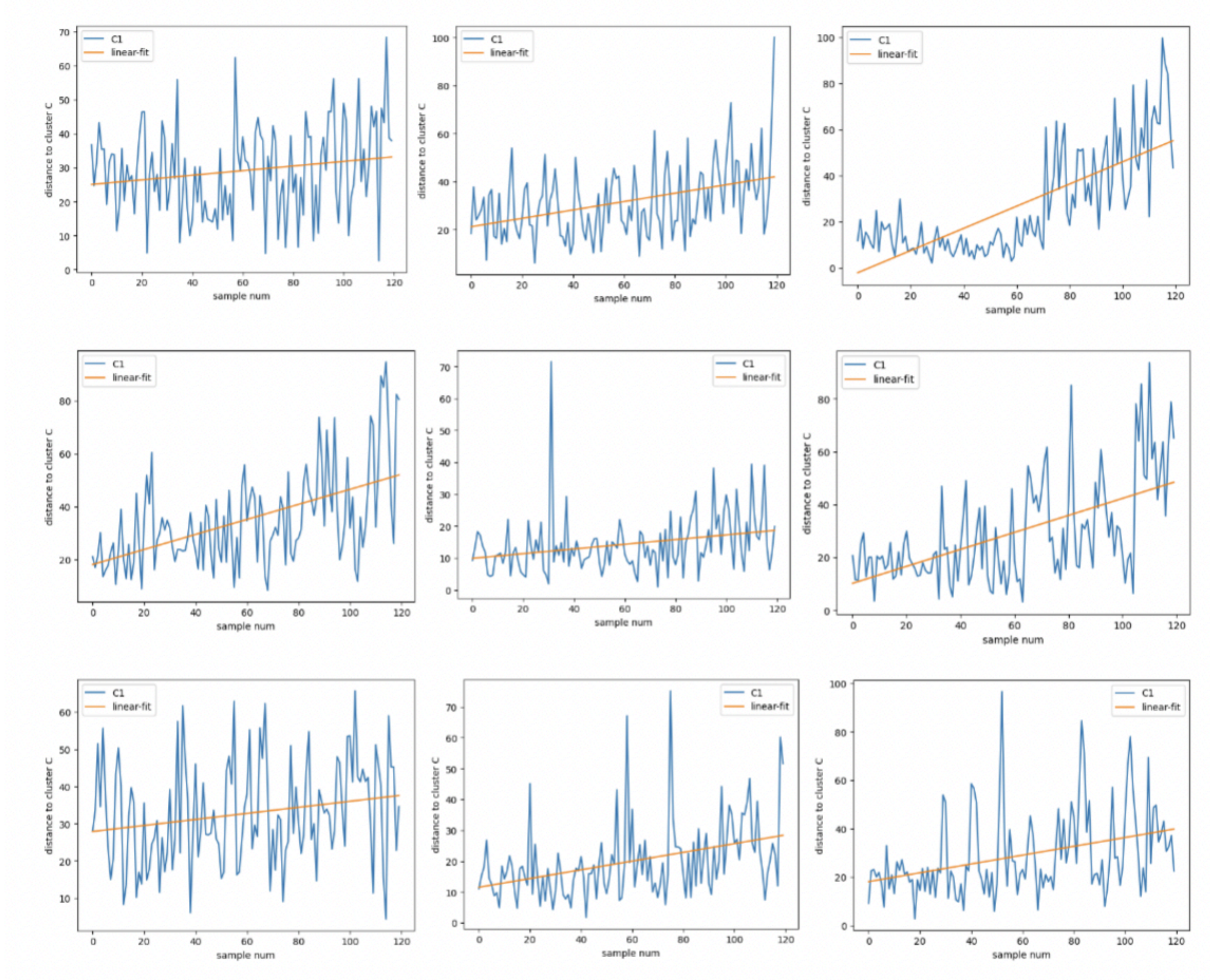


Figure 2 Sample plots of the distance from cluster and the slope for Individual #0-9. Note #6 has positive slope but its small.

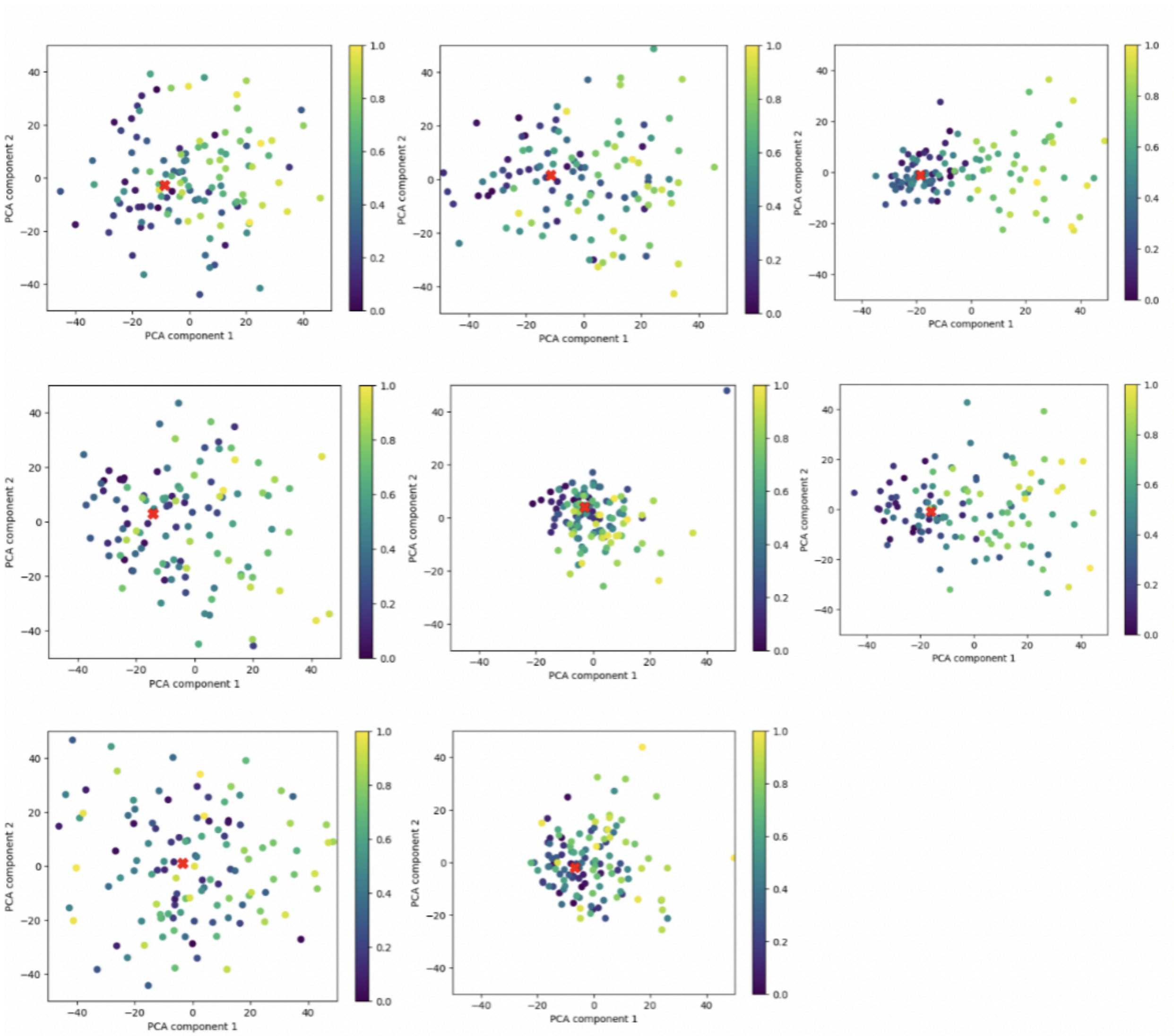


Figure 3: The respective clustering through PCA algorithm and the k-means cluster center marked by a red "X". The first 50 or so points are used in the computation of the cluster center by assuming this is a non-fatigue stage.

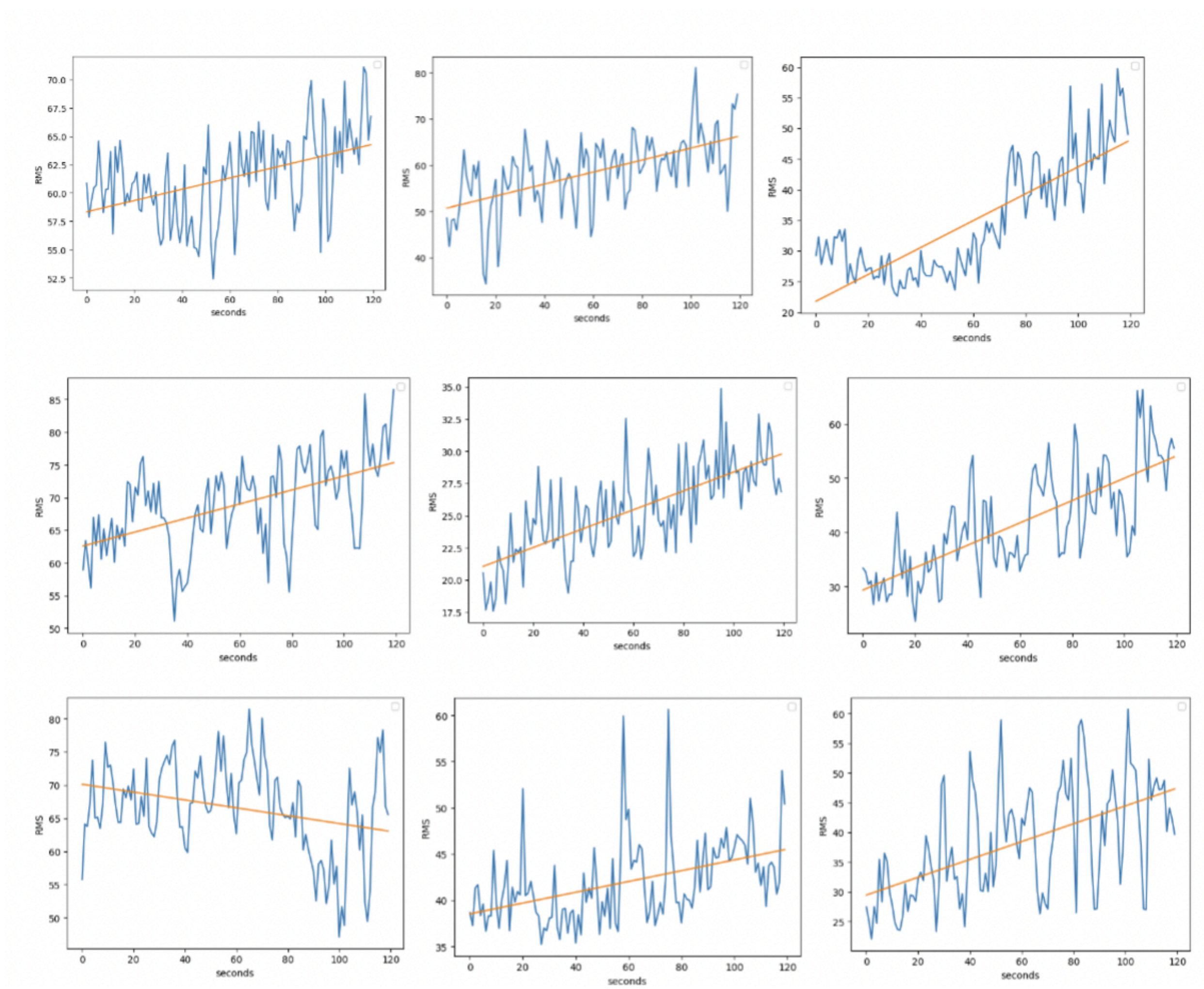


Figure 4: The RMS and the slope. Note the axis limits – most important is individual #6 (starting from 0) has negative slope.

July 20, 2023

- *Did some extra research applications of this topic + why this would be important to study*

Clinical:

- Basically, studying how the patients get fatigued if they have a disease versus healthy individuals

- Myopathy: any disease that affects the muscles that control voluntary movement – weakness, stiffness, etc.

- Clinical applications of HD-sEMG, subdivided into: (i) fatigue studies in neuromuscular disorders

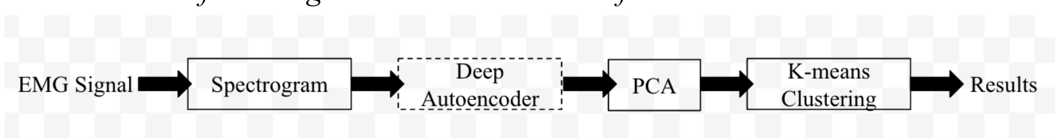
and chronic fatigue syndrome (CFS), (ii) motor neuron diseases (MND) and neuropathies, (iii) combination studies of MND, neuropathies and myopathies (iv) myopathies (including channelopathies), (v) positive muscle phenomena and (vi) MU firing rate.

Drost, G., Stegeman, D. F., van Engelen, B. G., & Zwarts, M. J. (2006). Clinical applications of high-density
surface EMG: a systematic review. Journal of Electromyography and Kinesiology, 16(6), 586-602.
Ergonomics and work-related:
- A number of studies using EMG for muscle activity during helicopter flights, heavy equipment, driving – basically any work that involves some vibration stress (use the first review paper below and follow its citations):

Mahdavi, N., Dianat, I., Heidarimoghadam, R., Khotanlou, H., & Faradmal, J. (2020). A review of work
environment risk factors influencing muscle fatigue. International journal of industrial ergonomics, 80,
103028.
de Oliveira, C. G., & Nadal, J. (2004). Back muscle EMG of helicopter pilots in flight: effects of fatigue,
vibration, and posture. Aviation, space, and environmental medicine, 75(4), 317-322.
Thuresson, M., Linder, J., & Harms-Ringdahl, K. (2003). Neck muscle activity in helicopter pilots: effect of
position and helmet-mounted equipment. Aviation, space, and environmental medicine, 74(5), 527-532.

June 23, 2023

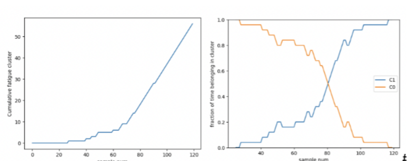
- *Decided on the following method + created this flow chart*



June 25, 2023

- *Decided to not use the deep autoencoder as it would be too complicated and time consuming for this project*

July 2, 2023

- *Met with Professor Jalal @ uofc today to go over my ideas for this project*
- *Need to make graphs more clear*
- *Explain study more in depth*
- *No longer using intersection of fatigue times that i had before (possibly inaccurate)*
- 

July 3, 2023

- *Worked on tweaking the codes for running the spectrograms and principal component analysis*
- *Codes currently not working — lots of bugs*
- *Tweaked some parameters (used different sample sizes etc.)*

July 10, 2023

- *Successfully ran all the EMG signal figures on all 15 channels*
- *https://docs.google.com/document/d/1LeFT5PsRFEjm9SUmDuBvi3T-uJT34yXK_Pc34H-djm8/edit?usp=sharing*

July 15, 2023

- *Lots of bugs in the code for running the spectrograms, but fixed the errors*
- *Ended up using 120 window frames*
- *Ran all spectrograms (in doc)*

July 22, 2023

- *Finally able to get the principle comments and graph the clusters*
- *Figured out that k=3 was sufficient, more key components did not make a huge difference, and less than 3 did not yield as good of a result*

July 23, 2023

- *Ran all 15 channels through the principle comment analysis code finished yesterday*
- *Successfully obtained all the graphs*

August 10, 2023

- *Began working on the code for the slope fitting*
- *Found base code on GitHub*

August 12, 2023

- *Looked at previous projects with slope fitting functions*

September 20, 2023

- *Started looking at code again after a break in the summer*

September 23, 2023

- *Edited the base code for the slope fitting of the cluster distances*
- *Found that the slope was much greater for PCA method compared to RMS*
- *Greater distance = more effective*
    - *True for all 15 channels*

September 30, 2023

- *Realized that some of the RMS slope results were actually negative — RMS method failed but PCA method still worked*

October 7, 2023

- *Started code for plotting a bar graph to see teh difference in slope values between PCA and RMS method for direct comparison — half finished today*

October 16, 2023

- *Finished code from last session, able to plot bar graphs for all channels that compared slope values*
- *Found out that proposed PCA method was better in all 15 scenarios compared to traditional RMS method*

October 22, 2023

- *Began to write up intro/research on the importance of muscle fatigue*

Muscular fatigue is defined as the decreased production of maximal force caused by exercise which is affected by differing types of muscle contractions in fatiguing exercises such as isometric contractions or dynamic concentric and eccentric contractions.

Muscular fatigue is a frequently encountered occurrence that imposes constraints on athletic prowess and extended physical exertion. Furthermore, it exacerbates constraints on daily functioning across diverse pathological scenarios, encompassing neurological, muscular, and cardiovascular disorders, along with the aging process

Understanding the underlying mechanics of muscle fatigue is important not only for optimizing athletic performances, but also understanding of health conditions that involve muscle dysfunction.

Studies have indicated a correlation between muscle fatigue and the prevalence of musculoskeletal injuries, particularly in activities such as running. Muscle fatigue also affects workers involved in vibration stress such as driving and heavy equipment.

Recent evidence has revealed that fatigue induces alterations in muscle activation patterns and kinematics, potentially increasing the susceptibility to injuries affecting both muscles and bones. These findings emphasize the need to explore how fatigue-induced changes in muscle mechanics can influence injury risks and inform injury prevention strategies

October 28, 2023

- *Got feedback from experts of this field at professors and students at the Alberta BME*
- *Ideas to possible do same study on different body parts*
- *Edited a few of the graphs and bits of the introduction*

November 3, 2023

- *Came up with the title of my project: recognition of muscle fatigue status based on clustering of EMG signals*

November 11, 2023

- *Began drafting up writing for the methods*

November 29, 2023

- *Started methods section*

The proposed method is an unsupervised approach so that we do not need to label the EMG signals for fatigue or not fatigue which is hard to do.

The idea of the proposed method is represented by the following block diagram

We extract the time-frequency features from the EMG signals and then perform clustering to see whether the fatigue or not fatigue signals/features can form two nice clusters (well separated). If two distinct clusters are formed, muscle fatigue can be identified using this approach.

The time-frequency feature extraction is based on principal component analysis (PCA):, either on spectrogram or representation of spectrogram using autoencoder

Typical EMG signal waveforms (channel 4 and channel 7, front and back) of individual #8 are shown as follows:

(using spectrogram pictures from channel 4 and 7)

December 18, 2023

- *Continued they method section writing*

Given an EMG signal, we used non-overlapping windows to compute spectrograms as shown in the following diagram. The spectrogram is computed using discrete time Fourier transform.

PCA transforms each of these spectrograms into K principal components. For illustration, we chose K=3 over 120 frames as shown in the following figures.

As we can see in both channels, PCAs with darker values are densely grouped on the left side and PCAs with yellow/green colors are more scattered on the right sides.

January 5, 2024

- *Finished methods*

.After PCA, the K-mean clustering algorithm is applied to the extracted features.

$$L = \sum_{n=1}^{N}\sum_{c=1}^{C}||P(k) - \mu_c||^2$$

where μ_c is the cluster center, N is the number of samples, C is the number of clusters (C= 2 here). P(k) are PCA values

If the PCA values clustered on the left mostly belong to non-fatigue data and the PCA values on the scattered cluster are mostly belong to fatigue, then clustering will be an effective way to recognize muscle fatigue from the EMG signal.

Assume that the EMG signals at the beginning of the exercise are likely to be non-fatigue and those at the end of the EMG signals are more likely to be fatigue. We compute the distance of all PCA features to the "non-fatigue" cluster center (the left one) along their time indices. If the features at the beginning belong to this cluster, the distance should be small. On the other hand, for the PCA features extracted at the end of EMG signal, the distance should be larger if they are those scatted PCA features at the right.

January 22, 2024

- *Completed analysis section + revised methods section*
- *Wrote the acknowledgments and citation section*

February 4, 2024

- *Filled out the ethics form and the other required form on the CYSF online platform, submitted*

February 15, 2024

- *Selected all the figures to be used on the trifold on presentation day*

February 18, 2024

- *Bought all the materials for the tri fold and put the title and headings on*

February 22, 2024

- *Printed all remaining materials and assembled trifold*

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