Effects of Bench Press on EKG Activity

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Lab 7, Group 6

Jesse Hurtado, James Dingle, Justin Hee

Abstract

Our final project is an analysis of the electrophysiological changes observed when a person is using the bench press, and comparing the observed changes data with physical data collected from the physical parameters of each bench press repetition, and the relative strength of each person. In other words, we are comparing the expressed electrophysiological changes of the body with the maximum power output of each person for a given weight on the bench press. Electrophysiology is the study of the electrical circuits that are integrated in human biological systems. For the purposes of this experiment, we are focused on the electrical activity of heart and chest muscles. The heart, and all the muscles in our body are innervated (activated by neurons) by efferent muscle neurons located in the anterior portion of the spinal cord. These neurons control the voluntary and involuntary activity of the muscles in our body, and receive electrical input from the brain. Much like a circuit, we can measure the voltage of these electrical impulses with a specific kind of voltmeter called an Electrocardiogram. At the cellular level, the outer membrane of muscle tissues, and most tissues of the body, acts as a capacitor, and separates positive and negative charge on either side of the membrane according to a principal called macroscopic electroneutrality, and the charge across the membrane is balanced at zero, and we would expect that a voltmeter across the membrane would read 0. Electroneutrality is violated when the conformation of the membrane changes, and transient voltage changes occur as a result of transient changes in current flowing across the membrane. These transient voltage changes are what give us the characteristic spikes that are seen in an EKG reading of heart activity. The spikes are the voltage changes across the membrane of the heart, and this is also the same principle for muscle activity, as we measure transient voltage changes across the neuromuscular junction (where the nerves meet the muscle tissue).

Introduction

With these concepts in mind, we set out to design an experiment that would correlate electrical activity with the bench press, and our hypothesis was that we expected there would be a positive correlation between voltage amplitude, power, and the weight we were benching. In other words, we expected that as we benched heavier weights, the magnitude of our EKG spikes would increase, and our power output would increase. To find our power outputs, we used the Arduino Uno ultrasonic sensor to measure distance and time data in order to solve for the velocity of our reps, and used this value to solve for power as power is energy over time, and we knew our energy from our velocity and change in distance, and a bit of simple math. We would do a set amount of reps, and record the muscle activity with an EKG obtained from Backyard Brains, a neuroscience research start up that is currently working to provide access to experimental technology and resources that would typically only be found in a research lab, to classrooms across the country[1].

[1] https://backyardbrains.com/products/muscleSpikerbox

Equipment

- Arduino Uno R3 controller
- Arduino extension board
- Power source (Laptop/Battery)
- Mini breadboard
- Jumper wires
- 1k ohm resistor
- 2k ohm resistor
- HC-SR04 ultrasonic sensor
- HC-06 Bluetooth modules
- bench press and weights
- Backyard Brains Heart and Brain SpikerBox EKG
- SpikeRecorder software

Methods

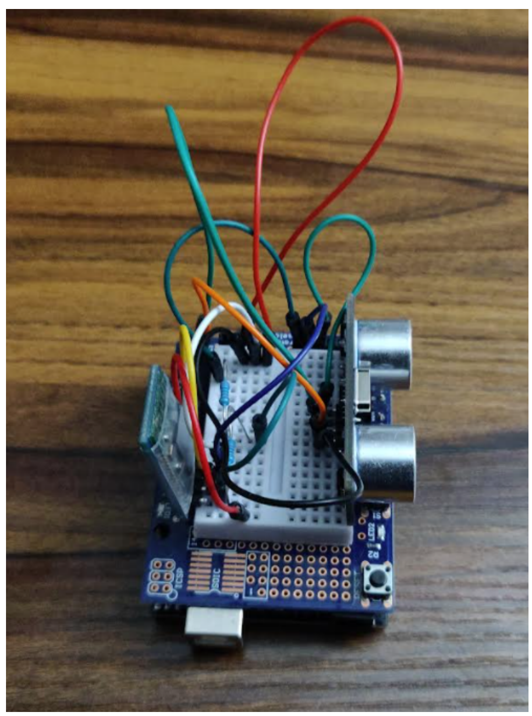


Figure 1: Arduino Uno setups with Ultrasound sensor and Bluetooth module attached

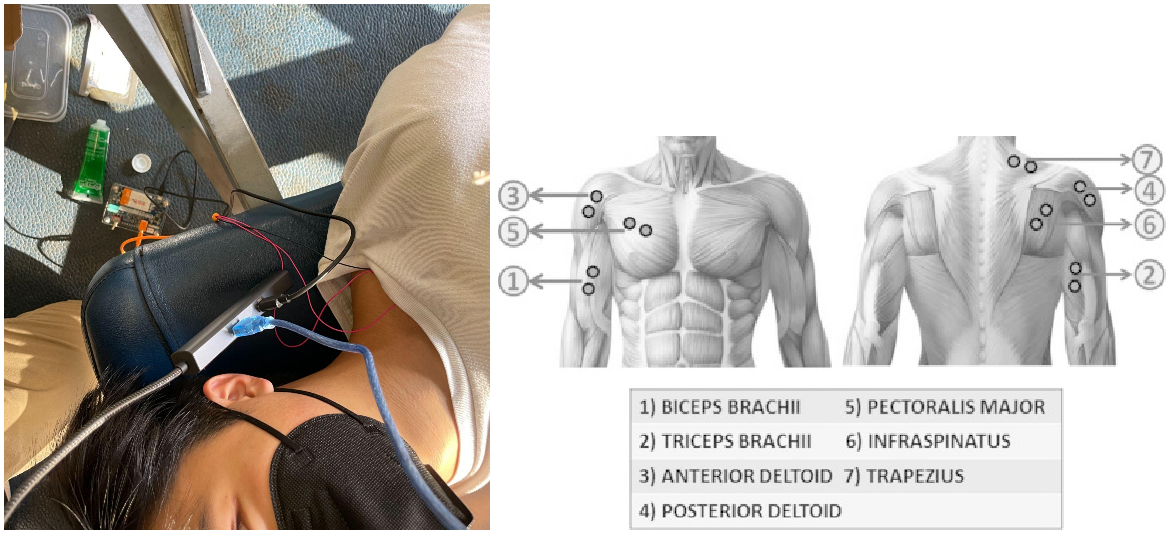


Figure 2: EKG attached to test subject at location 5 (Pectoralis Major)

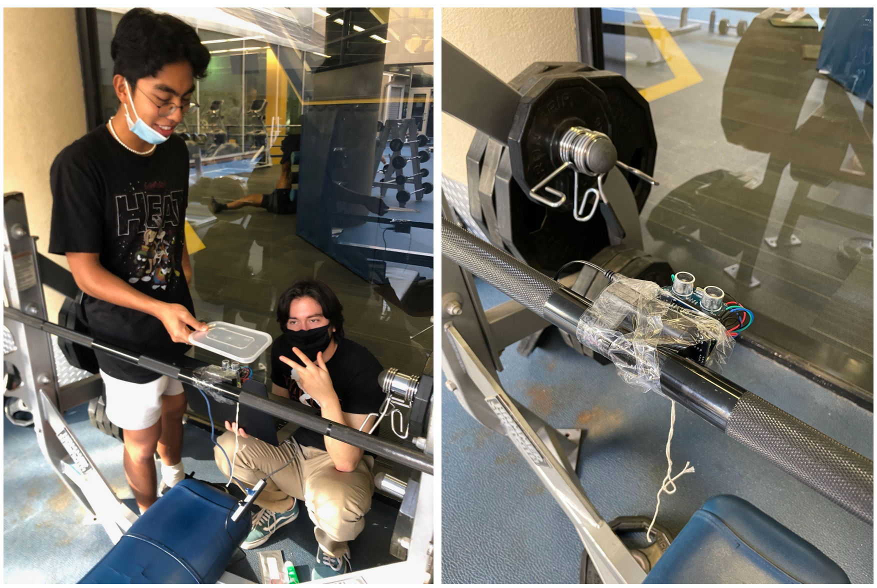


Figure 3: Arduino mounted to the barbell facing reflective surface

The experimental setup consisted of two main parts: the Arduino Uno and the EKG. The Arduino Uno was wired with the ultrasound and bluetooth modules according to Figure 1 and attached to the barbell. A reflective surface was placed above the Arduino in order to measure the distance traveled by the barbell (Figure 3). The EKG was attached to the test subject according to Figure 2, measuring the electrical signal output from the Pectoralis Major. We then followed the following procedure for each trial (also shown in Figure 4):

1. Test subject unracks the weight
2. Place a reflective surface above the Arduino
3. Start recording on both the EKG and Arduino at the same time
4. Test subject completes bench press

5. Stop recording on both the EKG and Arduino

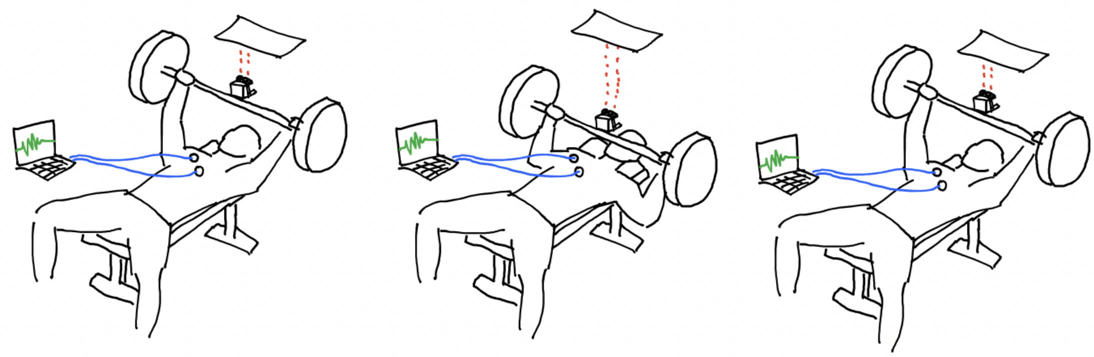


Figure 4: Experimental setup and procedure during bench press trial

This procedure was repeated over the course of 9 trials and 3 test subjects. The weights are shown in Table 1. The weight of the first set for each subject was the empty bar at 45 lbs, the weight of the second and third sets were around 50% and 80% of the subjects' one rep maxes. In addition to these trials, we also recorded baseline EKG readings at rest for each subject, to allow us to analyze the change in EKG amplitude during the actual exercise.

Person	Set 1 Mass	Set 2 Mass	Set 3 Mass
Justin	20.41 kg (45 lbs)	61.23 kg (135 lbs)	92.99 kg (205 lbs)
James	20.41kg (45 lbs)	34.02kg (75 lbs)	43.09kg (95 lbs)
Jesse	20.41kg (45 lbs)	34.02kg (75 lbs)	43.09kg (95 lbs)

Table 1: Mass for each trial and test subject

Results

The Arduino data was collected as a set of time and distance values of the barbell, and the EKG data was saved as a .wav file recording the electrical activity of the Pectoralis Major at a 10 kHz sample rate. However, the raw distance data was very messy, most likely due to the ultrasound sensor becoming offset from the reflective surface during the bench press. To counteract this, we manually removed the outliers from the csv files after examining the data. An example of this is shown in Figure 5.

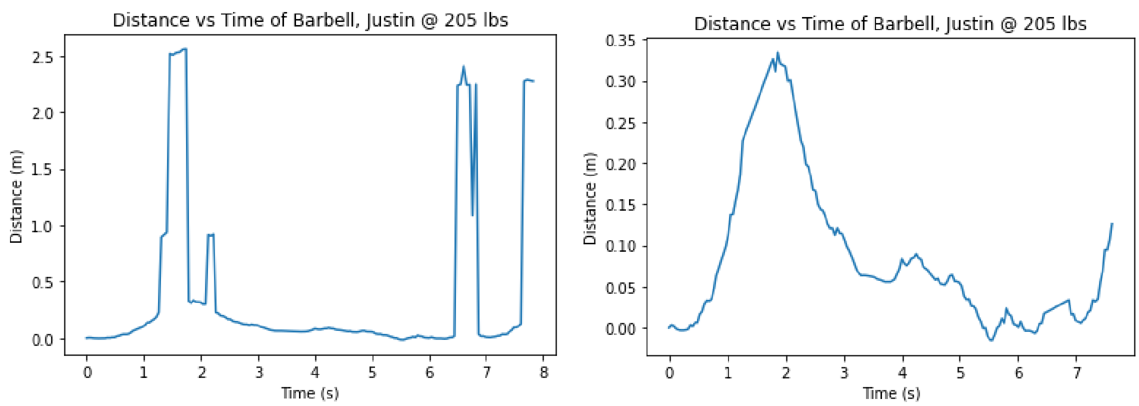


Figure 5: Initial distance data shown on the left; Data with outliers removed shown on the right

Once we had the cleaned distance data, we then used np.polyfit to find approximations of the velocity and error for the eccentric (weight going down) and concentric (weight going up) parts of the bench press (Figure 6). We then used the formula Power = Force * Velocity, where Force = mg, to calculate the power for the two halves of the movement. To get the uncertainty in the power, we used the error propagation formula for multiplication by a constant (as we took the mass and gravity values to be accurate).

$$\delta P = Fv(\delta v)/v = F\delta v$$

Because power is dependent on velocity, it has a direction and sign. In order to compare both the eccentric and concentric movements' powers, we decided to use the absolute value of the power.

```
linreg("Jesse", 95,65, 85)
```

```
Slope: -0.32368470785878783 ± 0.010433653553110578 m/s
Force: 422.7250644
Power: -136.8296389749013 ± 4.410566870165958
```

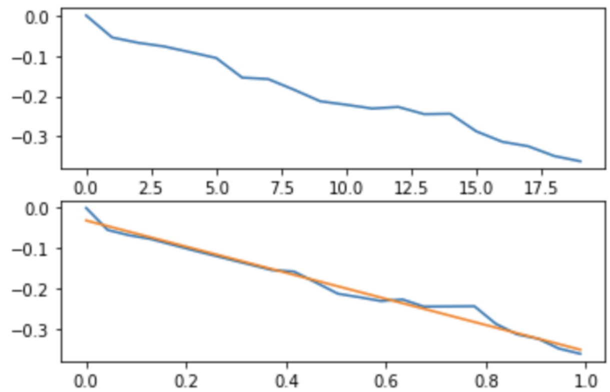


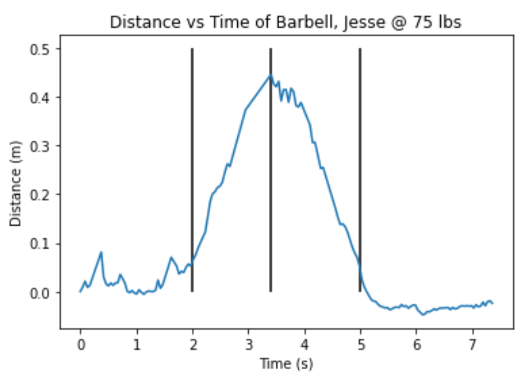
Figure 6: Linear approximation of the distance data allows us to calculate the velocity and power of the concentric half of Jesse's bench press at 95 lbs.

Trial	Force (N)	$V_{eccentric}$ (m/s)	$V_{concentric}$(m/s)	$\lvert P_{eccentric} \rvert$(W)	$\lvert P_{concentric} \rvert$(W)
Justin 45lb	200.22	.23 ± .0050	-.45± .0097	45.91 ± .99	90 ± 1.94
Justin 135lb	600.67	.21 ± .0049	-.44± .013	123.23 ± 2.95	262.44± 11 .46
Justin 205lb	912.23	.21 ± .012	-.15 ± .010	193 ± 11.3	138.20 ± 9.57
James 45lb	200.22	.22 ± .0068	-.20± .006 5	43 ± 1.37	39.48 ± 1.31
James 75lb	333.74	.12 ± .0020	-.17 ± .0039	40.76 ± .68	57 ± 1.29
James 95lb	422.71	.16 ± .0014	-.25 ± .0044	70 ± .59	104.44 ± 1.87
Jesse 45lb	200.22	.19 + .0049	-.25 ± .010	37.06 ± .99	50.12

					± 1.83
Jesse 75lb	333.74	.26 ± .0090	-.28 ± .0074	86.29 ± 3.56	94.84 ± 2.46
Jesse 95lb	422.71	.17 ± .013	-.31 ± .016	72.41 ± 5.67	136.83 ± 4.41

Table 2: Force, Velocity, and magnitude of Power for each trial's eccentric and concentric movements.

We decided to interpret the EKG data based on the average maximum amplitude of the electrical signals, as "The amplitude of [an EKG] signal has the potential to provide a measure of the magnitude of muscle force" (Roberts and Gabaldon)". To do this, we first used the Arduino data to find the intervals of the concentric and eccentric parts of the bench press (Figure 7).



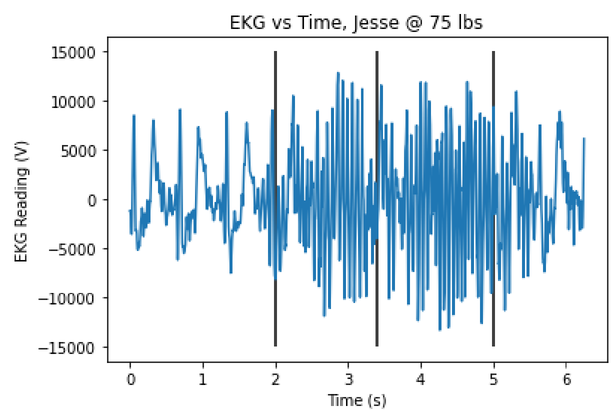


Figure 7: Using the distance vs time graph, we were able to pinpoint the intervals of the concentric and eccentric contractions and map them onto the EKG graph.

Then, we passed these intervals into code we wrote to identify all of the peaks in the data, meaning that the peak's neighboring values were both less than or equal to its own value. From there, we averaged those values to get an estimation of the amplitude of the EKG signal (Figure 8). Subtracting the resting EKG amplitude from these, we were able to quantify the increase in voltage during the bench press (Table 4).

```
averageGreater(data, 7000)
```

```
Peak values greater than 7000
7467
7892
7483
7493
7492
7289
7675
7756
8108
7594
Average: 7624.9
```

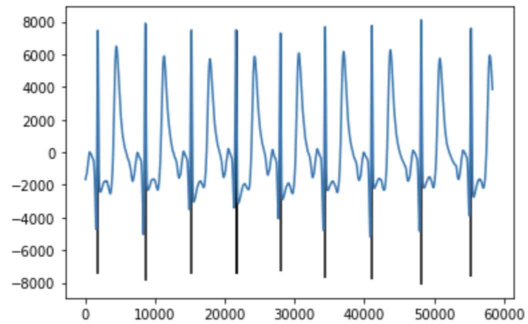


Figure 8: Estimating the EKG amplitude of one of our calibration datasets. First, we look at the data and identify which peaks we want to count. In this case, we only wanted to average the peaks over 7000, so we passed 7000 into the function. The black bars on the graph show the peaks that were identified, and their average is calculated.

Person	Resting BPM	Resting Average Peak Voltage (V)
Justin	70	.54
James	80	.99
Jesse	90	.77

Table 3: EKG data for each of the test subjects at rest. The average peak voltage was calculated using the method depicted in Figure 8.

Trial	Eccentric EKG Increase (V)	Concentric EKG Increase (V)

Justin 45lb	.10	.20
Justin 135lb	.49	.34
Justin 205lb	.35	.38
James 45lb	.02	.20
James 75lb	.10	.20
James 95lb	.26	.18
Jesse 45lb	.28	.16
Jesse 75lb	.24	.22
Jesse 95lb	.24	.22

Table 4: Using the calibration data from Table 3 as well as the eccentric and concentric EKG values calculated from each trial, we found the increase in EKG voltage from rest for the eccentric and concentric parts of each trial.

Finally, in order to investigate the relationship between power produced during a movement and increase in EKG amplitude, we plotted 18 points, each point corresponding to a movement (eccentric/concentric, weight, test subject).

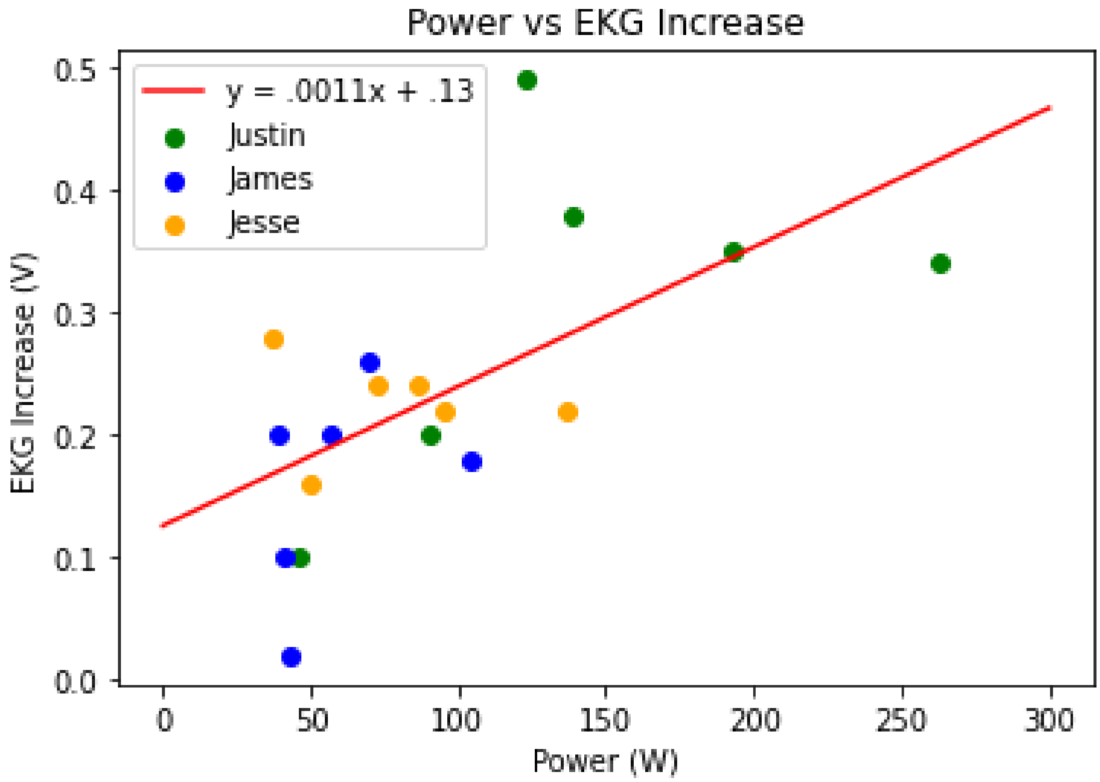


Figure 9: Power vs EKG increase for all 9 trials' concentric and eccentric contractions. While the linear regression line shows a positive trend, when we look at the data points for each test subject individually that trend disappears.

We graphed the Power (W) vs EKG Increase (V) data along with its regression and it came out with a correlation coefficient of .62 (Figure 9). On its own, this graph may show that there is a moderate positive correlation between the two variables. However, we come up with different results if we look at the individual datasets for each person.

As you can see, the green, blue, and orange dots (which are color coded for each person) are grouped together into respective groups. The greens (Justin) have the highest EKG Increases, the blues (James) have the lowest EKG increases, and the yellows (Jesse) are somewhat in the middle. This observation suggests that for each person, there is a similar power output and EKG increases no matter the weight. What this also suggests is that there were possibly other variables that affected these values that we did not account for. In a future experiment, we might try to take into account muscle mass or different lifting forms to investigate these further relationships.

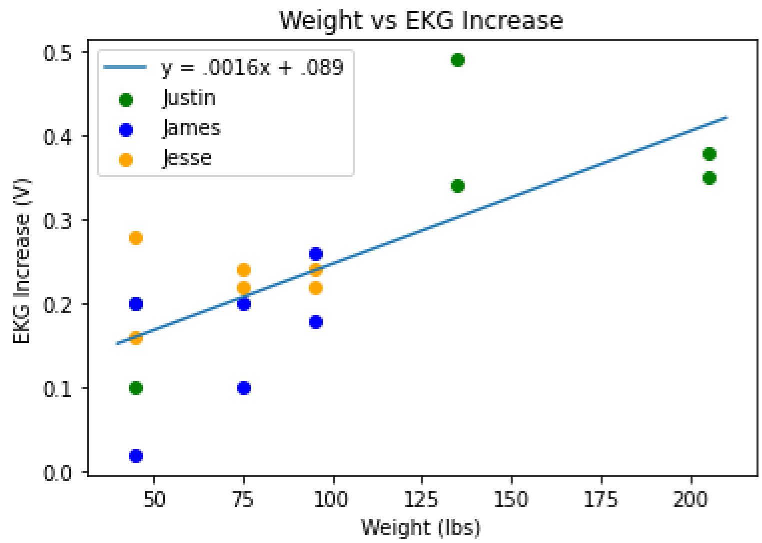


Figure 10: Weight vs EKG voltage increase for all 9 trials

As our Power vs EKG data was inconclusive, we also examined the relationship between weight lifted and EKG voltage increase (FIgure 10). Here, we see that the overall data also follows a stronger positive correlation, even within each person's trials. For the most part, a higher weight seems to correlate with a larger increase in voltage. This suggests that perhaps our velocity readings were the error, as the power is equal to weight * velocity. Somehow, when we multiply these values by the velocity they were moving at, the positive correlation turns into no correlation. This leads us to believe that Power is not an accurate predictor of the actual voltage level increase in the muscles, whereas the amount of force being exerted has a more conclusive relationship.

Conclusion

Based on our data we suppose the results to be inconclusive as to whether there may be a positive correlation between power and average spike voltage. More trials would be needed, however, there is a very weak positive trend. The maximum average spike voltage remained relatively constant across all experimental trials, meaning that it appears to max around 1.2 volts, and does not increase as the weight increases. The average resting potential was 0.7667 volts, while the average spike potential during muscle activity was approximately 1.2 volts. We conclude that our data does not support the hypothesis, and instead supports the null hypothesis that there is not a correlation between the voltage spikes and max power output. What seems to be the case is that the muscle spikes reach a voltage cap, an average output of about 1.2 volts during muscle activity is reached, and this is where the voltage generally stays at during the bench press, regardless of power. However, when we examine the relationship between weight and average spike voltage, we see a much stronger trend. This suggests that weight, rather than power, is the driving factor when determining EKG voltage. The errors we experienced greatly affected our data collection. Firstly, the ultrasound data we collected was not consistent because of the fact that we did not have a stable reflective surface for the sound waves to bounce off and record accurately. The result of this was our power values varied greatly between reps, and our velocity was near impossible to keep consistent with each trial, and so our power values were at the mercy of how well we held the small plastic surface above the sensor, and how well we could keep the bar steady, which was not well. Additionally, we only did one rep of each weight interval, which only gave us one set of data, and one set of EKG readings per each rep, which means our capacity to analyze this data was restricted to the one rep, and all the error was also contained in that same set, instead of taking multiple reps where we might have been able to further standardize the data based on multiple readings. The result of this error was very messy EKG spike readings that did not, at first, appear to be very conclusive with very large or very small outlier spikes, and no obvious trend, and no other data to compare it to. In the future, it would be much more efficient to have some way to standardize the movement of the bar, and also the data collection process itself, as there is a need to be as uniform as possible for the timing window of the data collection, and this is something we did not take care to do, and were forced to make do with the data we had, with no real reference. Nonetheless, I believe my group and I still enjoyed conducting the experiment, and observed some electrophysiological trends amongst the three of us and gained valuable practice using the concepts taught in Physics 4AL.

References

Antuvan, Chris Wilson & Bisio, Federica & Marini, Francesca & Yen, Shih-Cheng & Cambria, Erik & Masia, Lorenzo. (2016). Role of Muscle Synergies in Real-Time Classification of Upper Limb Motions using Extreme Learning Machines. Journal of NeuroEngineering and Rehabilitation. 13. 10.1186/s12984-016-0183-0.

Roberts, Thomas J, and Annette M Gabaldón. “Interpreting muscle function from EMG: lessons learned from direct measurements of muscle force.” Integrative and comparative biology vol. 48,2 (2008): 312-20. doi:10.1093/icb/icn056