# Team #501

## BE 312 Spring 2021 Lab 3, EMG

**Sunday, April 18th, 2021**

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## Abstract

In this experiment, we used electromyography (EMG) to measure the activity of skeletal muscles in the dominant and non-dominant arms of participants. Participants had three electrodes connected to their arms to measure the overall action potentials in the muscles, known as the Integrated EMG, when exerting force. Our electrode setup was used to measure the maximum clench force of both hands, tonus reaction force, and rate of fatigue over a period of time. We normalized our raw data, integrated data, and force data across these experimental categories to determine the correlation between participant background information and data trends irrespective of individual strength. Simply put, normalization allows us to look at data as a measure of a person's percent output of their maximum force and EMG data. Combined with the use of confidence intervals alongside our data, we were able to show the variances between dominant and non-dominant hand data in regard to a participant's skeletal muscle strength.

# Questions

## Short Clench Tests (practice with normalization)

**1. What relationship do you expect to see between the integrated EMG and clench force? Explain your answer.**

The integrated EMG value is the average of the signal over a set period of time, which should give an indication of muscle activity. Therefore, it would be expected that the integrated EMG would increase along with the clench force, since greater muscle activation would be required to apply a greater level of force.

**2. Find the confidence interval (95%) on the average of the integrated EMG during each clench (25%, 50%,75%, and 100%) for all the subjects in your data set. Create a bar (horizontal) chart to represent this data with 25%, 50%, 75%, 100% groups as the dependent variable and average EMG as the independent variable. Include error bars that represent the 95% range on the EMG estimates. (This is an example of unnormalized data.)**

Using Excel, we found the average and standard deviation of the integrated EMG for each clench level. We averaged left and right hands together since that should not significantly affect the average EMG levels.

Table 1: Average and Standard Deviation of Integrated EMG at Each Clench Level

| | 25% | 50% | 75% | 100% |
|---|---|---|---|---|
| Average | 0.0617 | 0.110 | 0.171 | 0.251 |
| St Dev | 0.0343 | 0.0613 | 0.0874 | 0.119 |

Using this data we calculated a 95% confidence interval around each average, using a count of 69.

25% Clench Level Integrated EMG

95% $C.I. \ = \ 0.0617 \pm 1.96(0.0343/sqrt(69))$

95% $C.I.\ is\ 0.0617 \pm 0.00413$

95% $C.I.\ range\ is\ from\ 0.0536\ to\ 0.0698$

50% Clench Level Integrated EMG

95% $C.I. \ = \ 0.110 \pm 1.96(0.0613/sqrt(69))$

95% $C.I.\ is\ 0.110 \pm 0.00738$

95% $C.I.\ range\ is\ from\ 0.0955\ to\ 0.124$

75% Clench Level Integrated EMG

95% $C.I. \ = \ 0.171 \pm 1.96(0.0874/sqrt(69))$

$95\%\ C.I.\ is\ \ 0.171 \pm 0.0105$
$95\%\ C.I.\ range\ is\ from\ 0.150\ to\ 0.191$

100% Clench Level Integrated EMG
$95\%\ C.I.\ \ =\ \ 0.251 \pm 1.96(0.119/sqrt(69))$
$95\%\ C.I.\ is\ \ 0.251 \pm 0.0143$
$95\%\ C.I.\ range\ is\ from\ 0.223\ to\ 0.279$

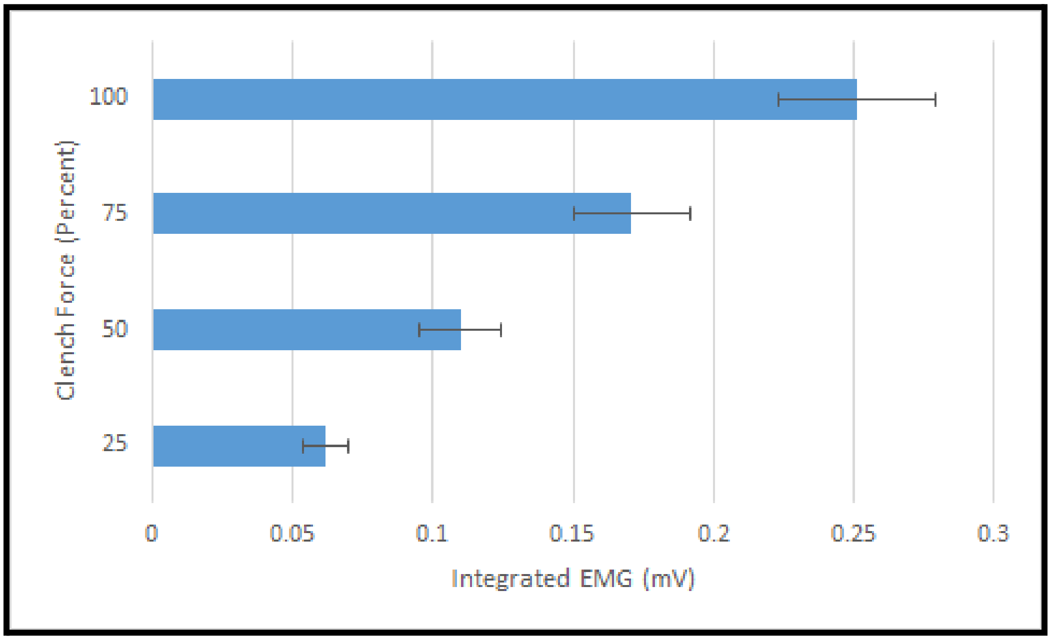


*Figure 1: Average Integrated EMG at Each Clench Level.* The average EMG voltage is shown with the solid bars, while the error bars represent the 95% confidence interval around that average.

**3. Make a scatter plot of the force vs integrated EMG generated during the four short clenches. Include a linear trendline. (This is also unnormalized data.)**

For problem three, we took multiple approaches to this problem. First, we created four scatter plots for each of our lab group's members using their dominant hand data. Second, we created a collated dataset from these four scatter plots, creating a unified scatter plot for our group. Finally, we created two collated scatter plots for all of the participants in Section A, using dominant and non-dominant data, with the exclusion of participant 3 in group 103 and participant 1 in group 204. These datasets were excluded due to clear error in the form of negative force values. An additional data set in the non-dominant Section A plot was left blank, and was omitted. Participant 1 in group 204 was not erroneous and therefore not excluded in the non-dominant dataset

The following scatter plots are our individual group member plots. The plots are color coded according to the colors of each participant's data cells in the spreadsheet. Mean Int. EMG is plotted on the x axis, while Mean Force is plotted on the y axis. At the top of the scatter plot, the equation of the linear trendline of the dataset is shown.

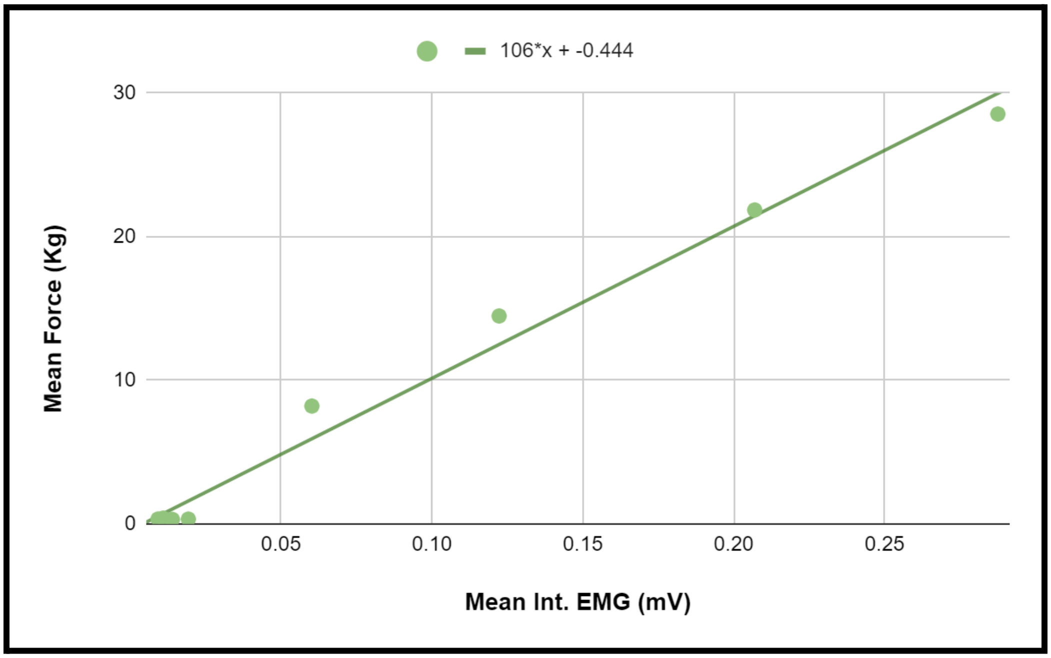


*Figure 2: Scatter plot of Mean Force (Kg) vs. Mean Int. EMG (mV) for participant 1 in group 0501*

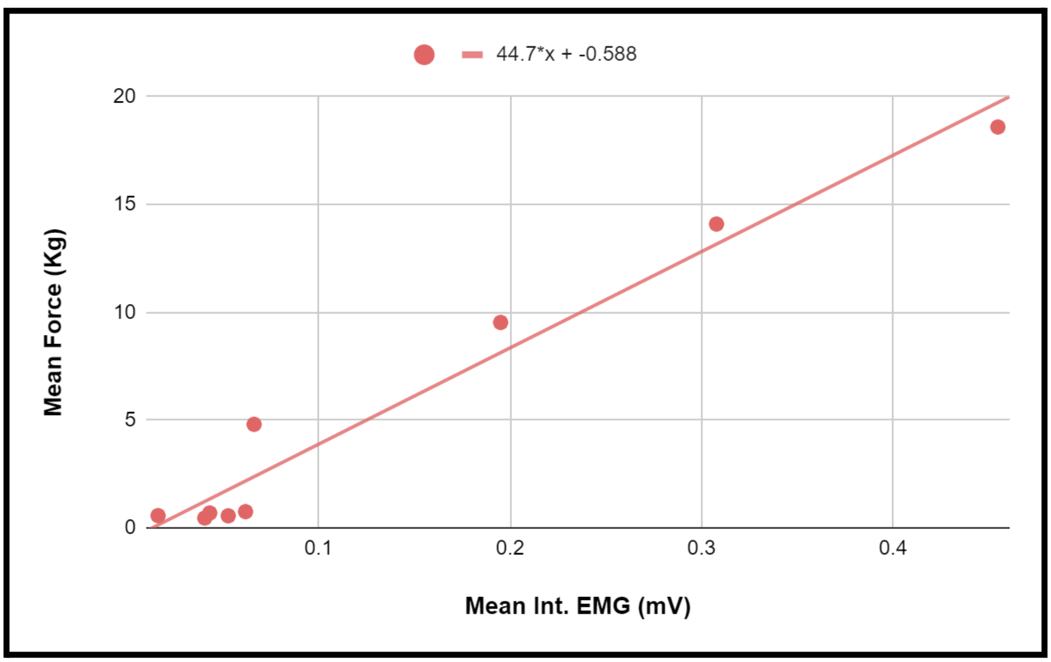


*Figure 3: Scatter plot of Mean Force (Kg) vs. Mean Int. EMG (mV) for participant 2 in group 0501*

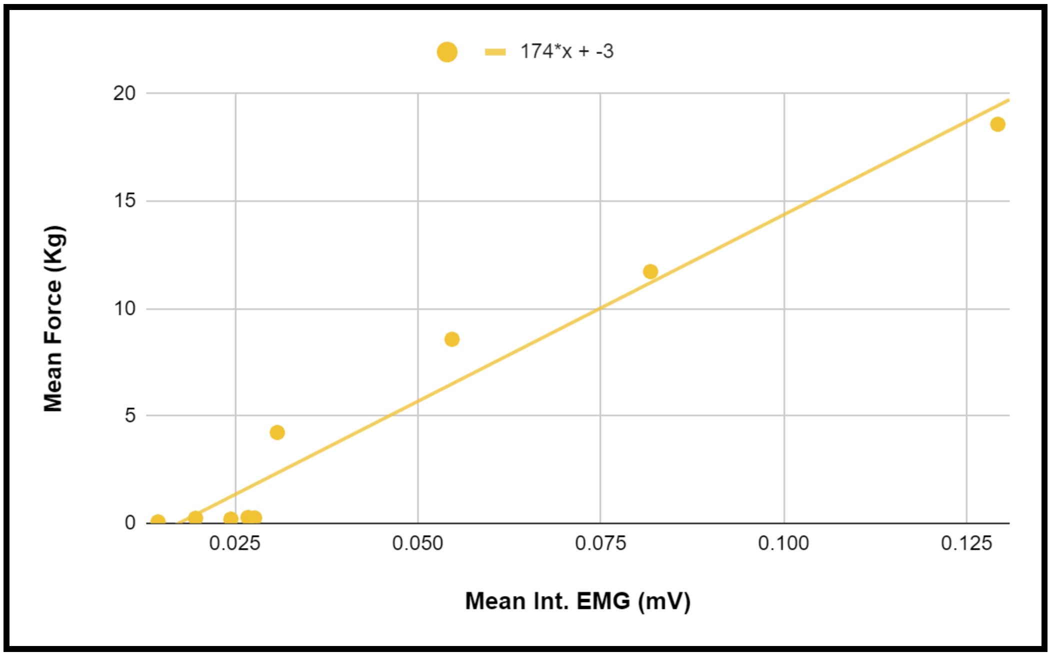


*Figure 4: Scatter plot of Mean Force (Kg) vs. Mean Int. EMG (mV) for participant 3 in group 0501*

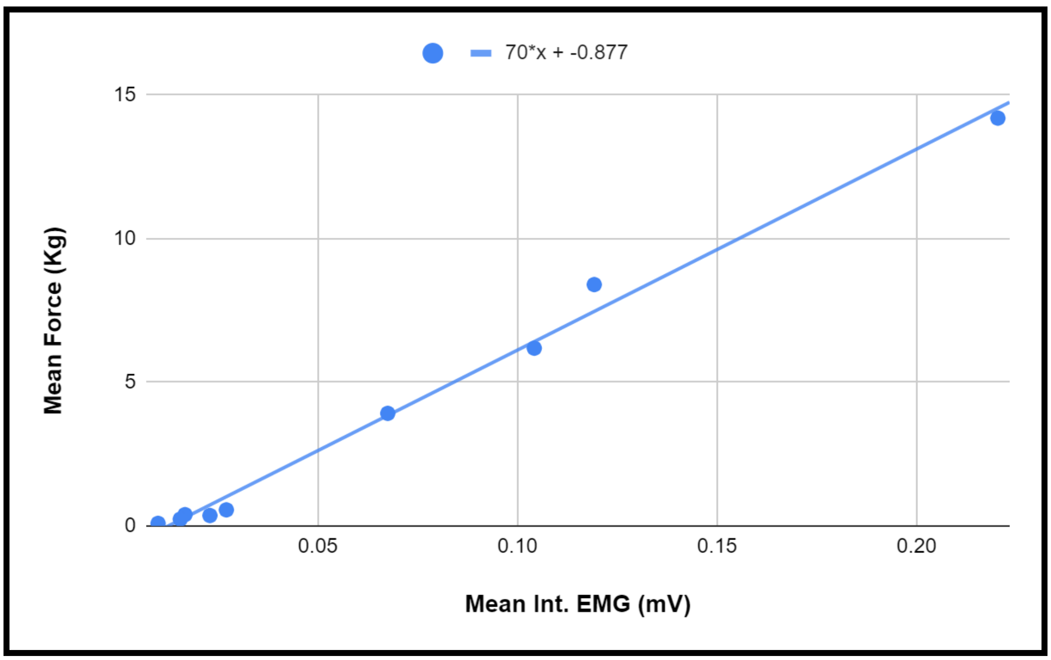


*Figure 5: Scatter plot of Mean Force (Kg) vs. Mean Int. EMG (mV) for participant 4 in group 0501*

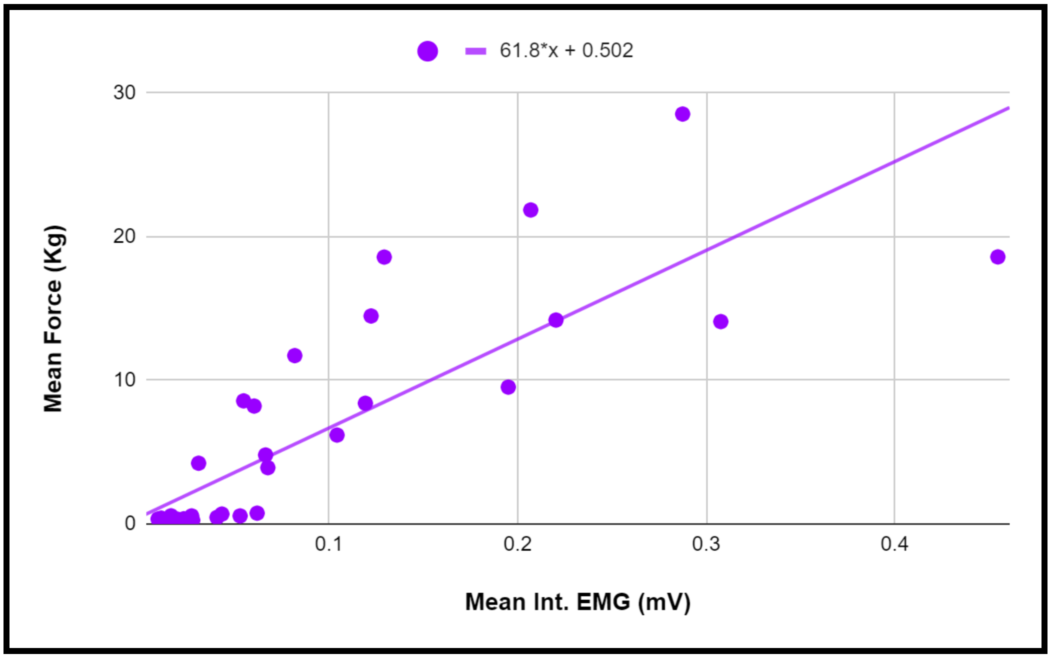


*Figure 6: Scatter plot of Mean Force (Kg) vs. Mean Int. EMG (mV) for all participants in group 0501*

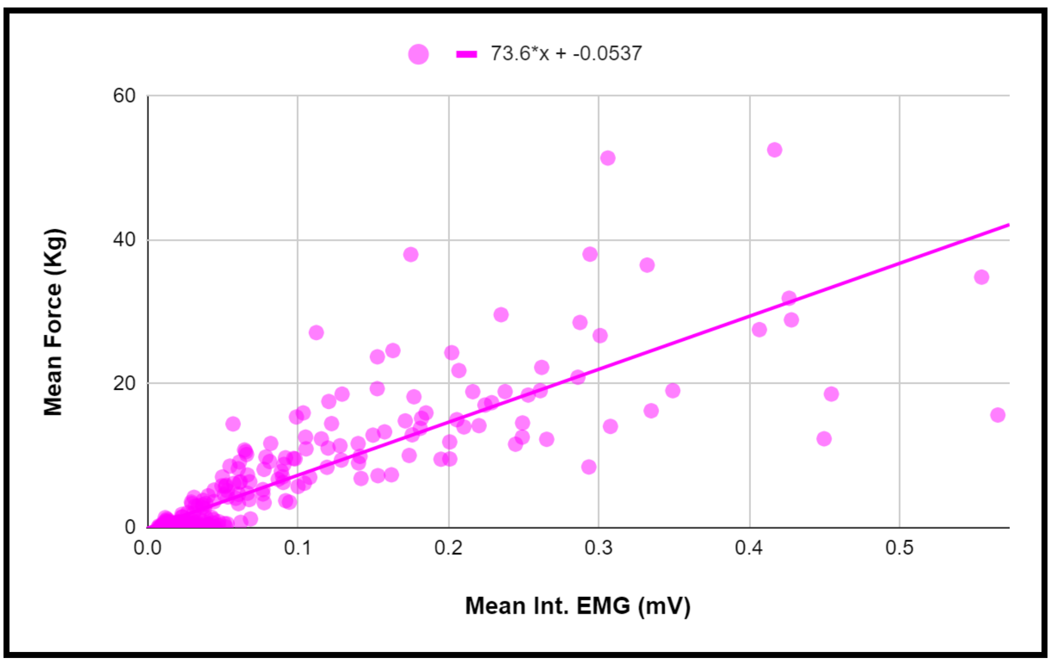


*Figure 7: Scatter plot of dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV) data for all participants in section A, excluding two datasets with erroneous negative force values.*

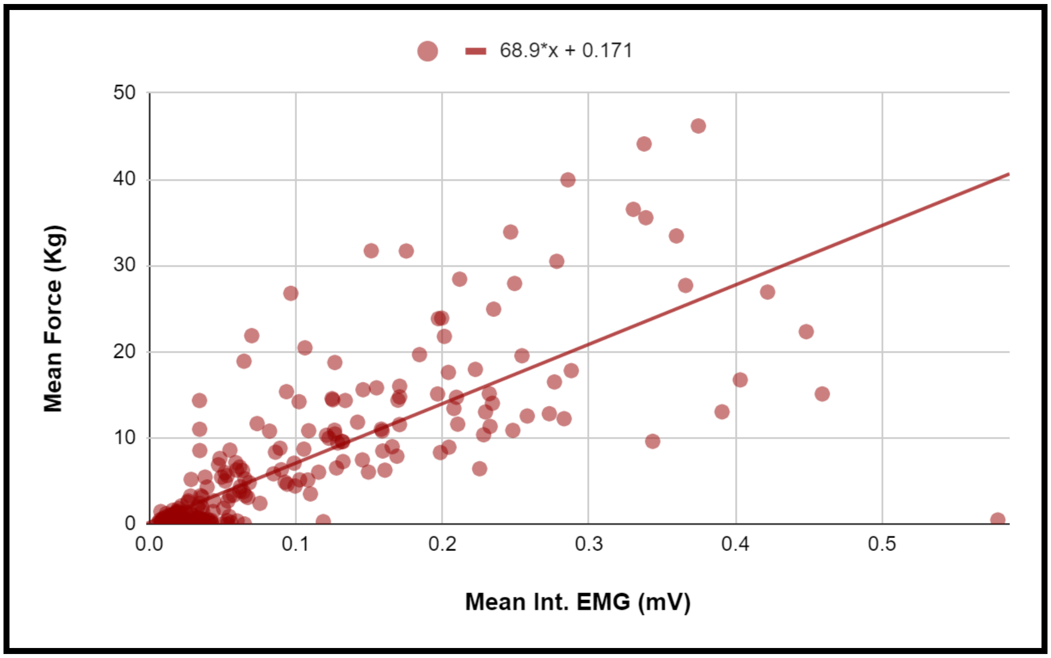


*Figure 8: Scatter plot of non-dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV) data for all participants in section A, excluding two datasets with erroneous or missing values.*

**4. For each subject, normalize their data by dividing the integrated EMG data by their "100%" integrated EMG value to get a % change in EMG from max. Do the same for force so you get a % change from max force. Create a scatter plot of % force vs. % integrated EMG for all subjects. Include a linear trendline. (This is normalized data.)**

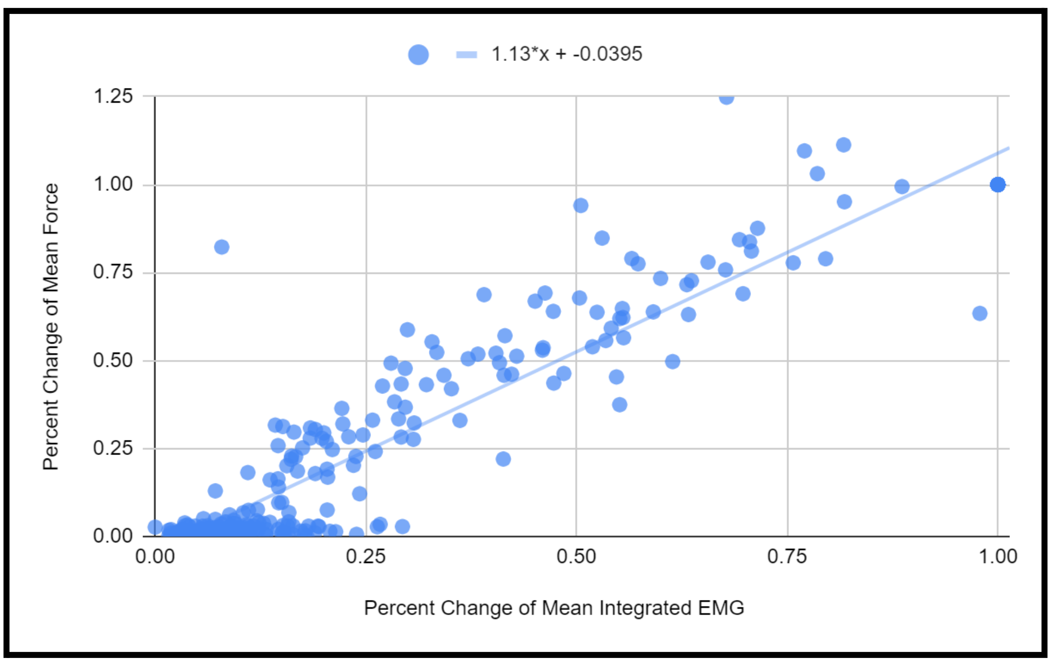


*Figure 9: Normalized scatter plot of dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV) data for all participants in section A, excluding two datasets with erroneous negative force values.*

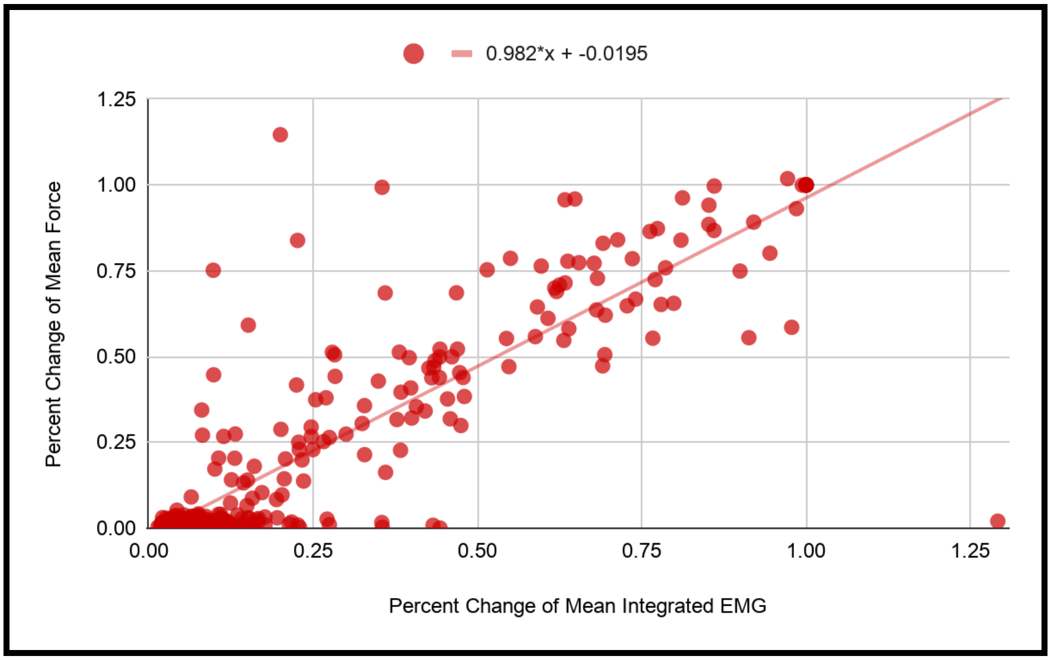


*Figure 10: Normalized scatter plot of non-dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV) data for all participants in section A, excluding two datasets with erroneous or missing values.*

**5. Which of these graphs shows the clearest relationship? Does this graph agree with your expectation from question 1? Explain your answer.**

The normalized graphs show the clearest relationship between force and integrated EMG. Compared to the unnormalized data, there is much less variation in the data points in the plots created with normalized data. The positive and linear relationship between % force and % integrated EMG agrees with the expectation from question 1. This expectation being that integrated EMG would increase as clench force increased.

**6. Make a similar graph to the one you selected in the previous question, but use the raw EMG data instead of integrated. Does this plot agree with your expectation? Explain your answer**.

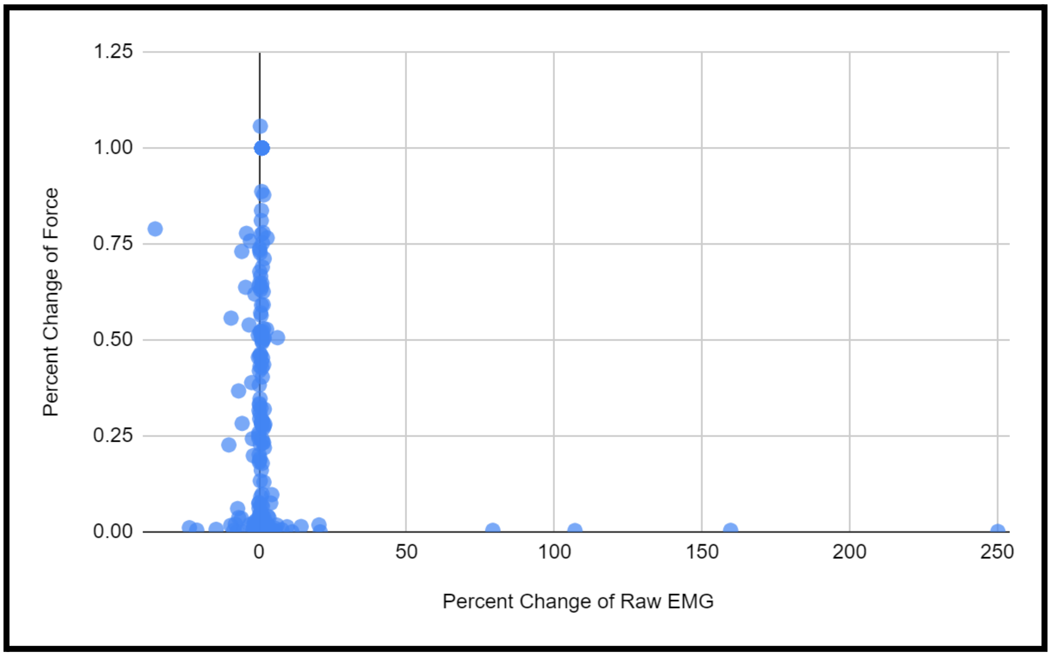


*Figure 11: Normalized scatter plot of dominant-handed Mean Force (Kg) vs. Mean Raw EMG (mV) data for all participants in section A, excluding two datasets with erroneous or missing values.*

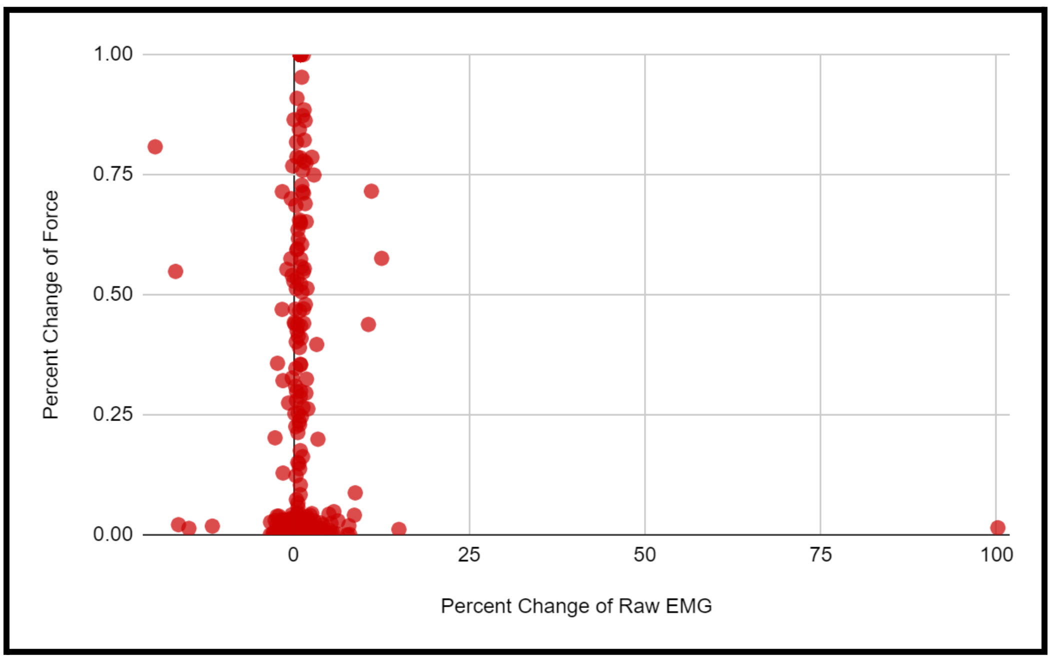


*Figure 12: Normalized scatter plot of non-dominant-handed Mean Force (Kg) vs. Mean Raw EMG (mV) data for all participants in section A, excluding two datasets with erroneous or missing values.*

The above plots, Figures 11 & 12, do not agree with the expectation that the EMG values would increase as clench force increased. The figures produced with raw EMG data shows no clear relationship between the normalized raw EMG data and force values. The stark difference in clarity between the relationships outlined in figures produced with raw and integrated EMG data stems from the high level of variability and noise of the raw data. Raw EMG data has a high level of noise since the signal produced accumulation of many action potentials occurring in the muscle cells of the arm. The normalized integrated EMG data produced a scatter plot that delineated a positive relationship with clench force by averaging muscle activity and therefore reducing the amount of variability.

# Tonus Short Clenches

**7. What relationship do you expect to see between tonus and muscle activity just before the tonus measurement (e.g. how does tonus 1 relate to clench 1)? Explain your answer.**

The brain subconsciously adjusts how a skeletal muscle contracts, which in return controls the activity of the skeletal muscle fibers. When the skeletal muscles are in resting positions there is still a slight contraction state, which is also known as tonus. Since the activity just before the tonus is the clench and the clench is increasing each time, we would expect the tonus to also increase as the clench increases. The subject is knowingly increasing the strength of the clench each time, which in return increased their tonus each time. Although the subject tries to relax their muscle for each tonus measurement, they are unconsciously increasing their tonus strength each time because their muscles are used to increasing their clench strength each time. The subjects muscles may try to relax for each tonus but they are relaxing less and less each time due to the subject increasing their clench.

**8. Do you see this relationship? Use a graphic to help explain your answer. Hint: you probably want to normalize, but it won't be exactly the same normalization that we did above.**
We can see the relationship in the dominant hand by the graphics, the tonus is increasing as the clench is increasing. This allows us to conclude that there is a relationship between clench and tonus for the dominant hand. The relationship is seen well for the non-dominant hand, as the clench increases, the tonus isn't changing that much. This allows us to conclude that there is no relationship between clench and tonus for the non-dominant hand.

The tonus dominant hand had an average mean force of 0.0224 and a force standard deviation of 0.011, and an EMG average of 0.361 and an EMG standard deviation of 0.322. The clench dominant hand had an average mean force of 0.150 and a force standard deviation of 0.116, and an EMG average of 12.5 and an EMG standard deviation of 9.54.

The tonus non-dominant hand had an average mean force of 0.0231 and a force standard deviation of 0.0133, and an EMG average of 0.471 and an EMG standard deviation of 0.529. The clench non-dominant hand had an average mean force of 0.150 and a force standard deviation of 0.104, and an EMG average of 12.4 and an EMG standard deviation of 9.54.

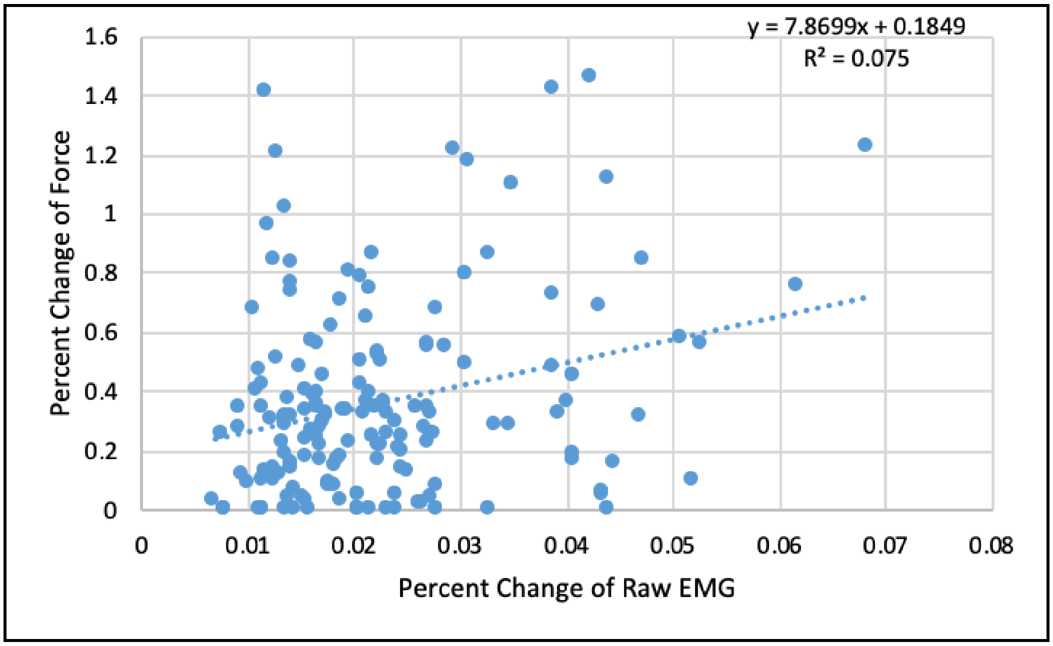


*Figure 13: Tonus scatter plot of dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV) data for all participants in section A, excluding two datasets with erroneous or missing values.*

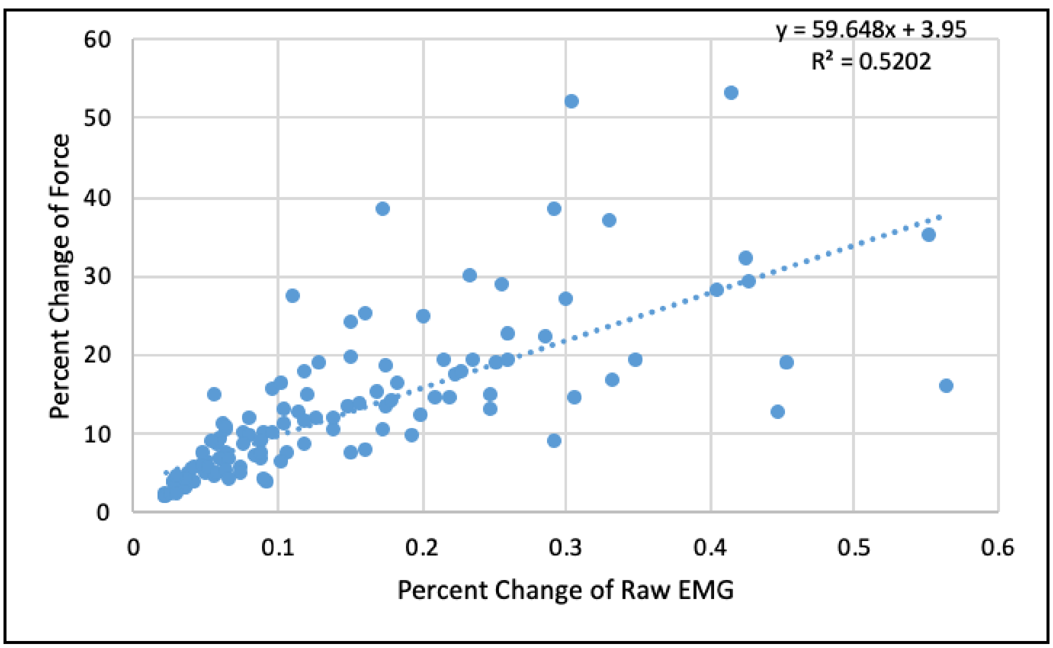


*Figure 14: Clench scatter plot of dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV) data for all participants in section A, excluding two datasets with erroneous or missing values.*

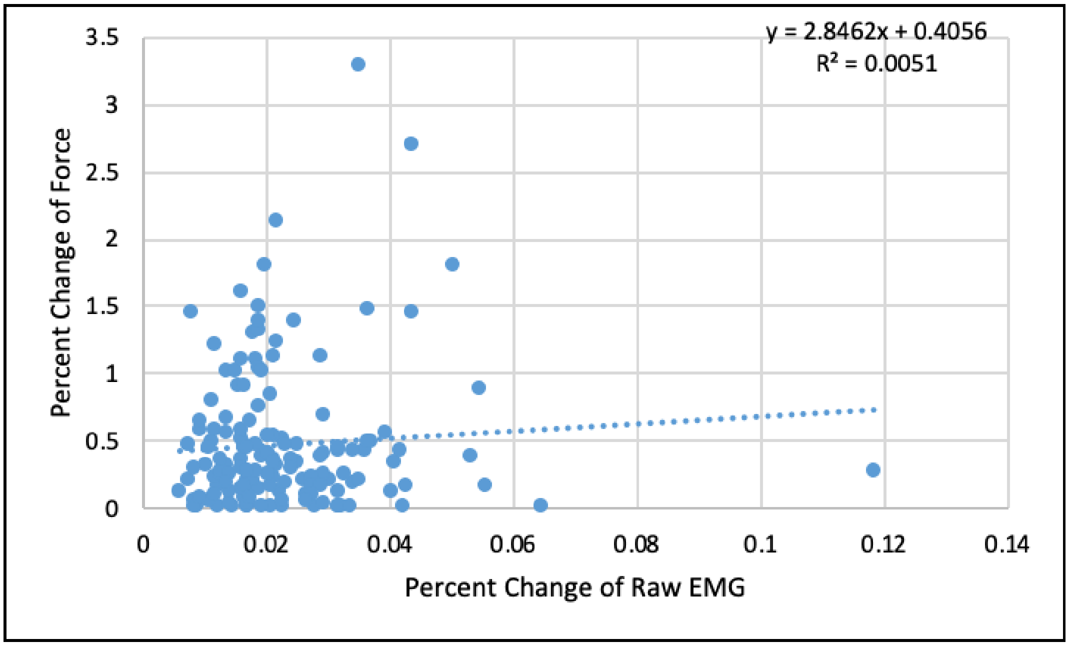


*Figure 15: Tonus scatter plot of non-dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV) data for all participants in section A, excluding two datasets with erroneous or missing values.*

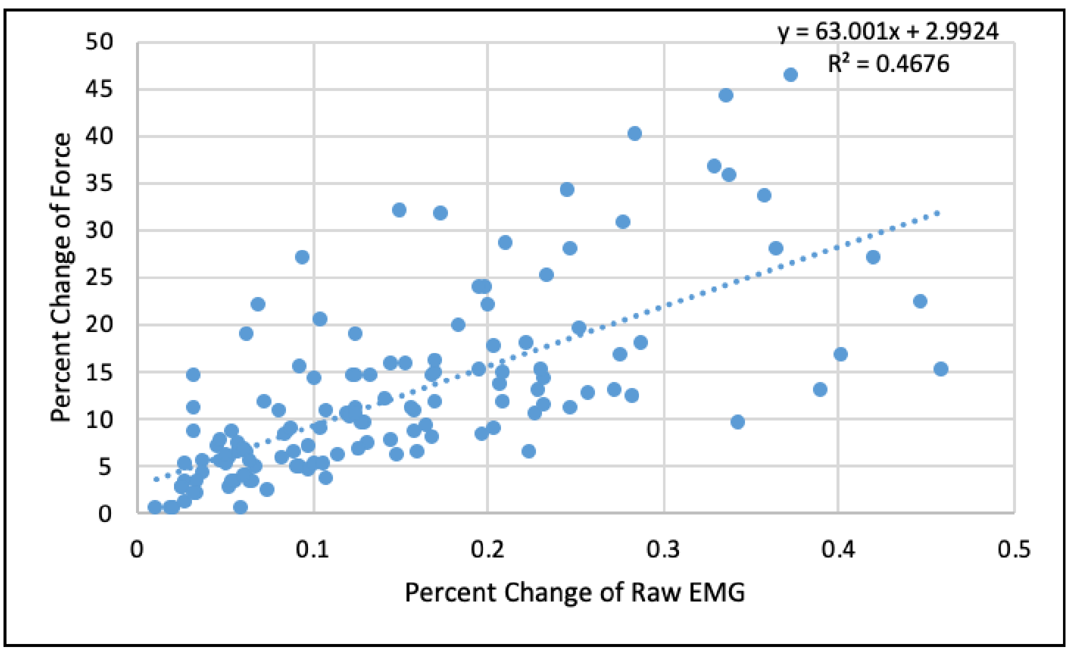


*Figure 16: Clench scatter plot of non-dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV) data for all participants in section A, excluding two datasets with erroneous or missing values.*

# Fatigue

**9. What relationship do you *expect* to see between max clench force and fatigue time (75% max, 50% max)? Explain your logic.**

We would expect to see the fatigue time increase as the max clench force decreases. This is because it is easier to maintain a lower level of force for longer periods of time. Maintaining maximum clench force is easy at first but can quickly become tiring. A moderate clench force, however, can be maintained for a longer period of time before it becomes tiring. This means it takes a longer time for the individual to fatigue to the point where they can no longer maintain that force level.

**10. Does the data show this relationship from Q9? Include a graphic to help explain your answer.**

To compare clench force and fatigue time, we first found the average time differences to go from one clench level to the other. The time differences for 100% to 75% and 100% to 50% were given in the data, so we were able to calculate the time difference for 75% to 50%. We used Excel to calculate the average time differences and their standard deviations. Then we made 95% confidence intervals around these averages. The dominant hand group had 35 participants while the non-dominant hand had 33 participants. This is due to one person not recording data and another person recording a negative time difference for their non-dominant hands. These averages and confidence intervals are shown in Figure 13 and Figure 14.

The time difference between 75% and 50% clench force was found by calculating the difference between the recorded time differences. For example, the first subject in the data sheet recorded time differences of 2 and 5 seconds for 75% and 50% respectively. The time difference for 100% to 75% is 2 seconds, while the time difference between 75% and 50% is 5 - 2= 3 seconds.

Our data shows that fatigue time increases as max clench force decreases. The average time difference was significantly larger when going from 75% to 50% than when we went from 100% to 75%. This shows that fatigue time is inversely related to max clench force.

Dominant Hand 100% to 75% Time Difference

$95\%\ C.I. \ = \ 7.471 \pm 1.96(5.307/sqrt(35))$

$95\%\ C.I.\ is\ 7.471 \pm 0.897$

$95\%\ C.I.\ range\ is\ from\ 5.713\ to\ 9.230$

Dominant Hand 75% to 50% Time Difference

$95\%\ C.I. \ = \ 14.686 \pm 1.96(12.941/sqrt(35))$

$95\%\ C.I.\ is\ 14.686 \pm 2.187$

$95\%\ C.I.\ range\ is\ from\ 10.398\ to\ 18.973$

Non-Dominant Hand 100% to 75% Time Difference

$95\%\ C.I. \ = \ 7.297 \pm 1.96(5.561/sqrt(33))$

$95\%\ C.I.\ is\ 7.297 \pm 0.968$

$95\%\ C.I.\ range\ is\ from\ 5.399\ to\ 9.194$

Non-Dominant Hand 75% to 50% Time Difference

$95\%\ C.I.\ =\ 15.348 \pm 1.96(14.548/sqrt(33))$

$95\%\ C.I.\ is\ 15.348 \pm 2.533$

$95\%\ C.I.\ range\ is\ from\ 10.385\ to\ 20.312$

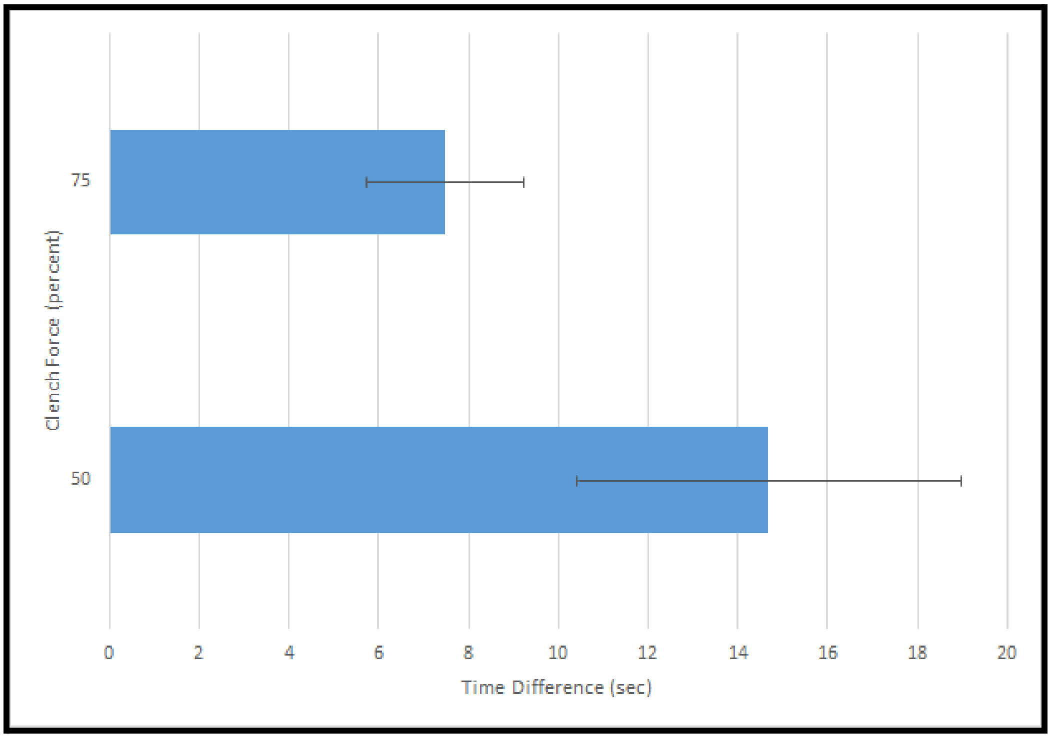


*Figure 17: Clench Force vs Time Difference for Dominant Hand.* This figure shows the time difference to reach a clench force level from the previous level, 100% to 75% then 75% to 50%. The solid bar shows the average time difference, and the error bars show 95% confidence intervals.

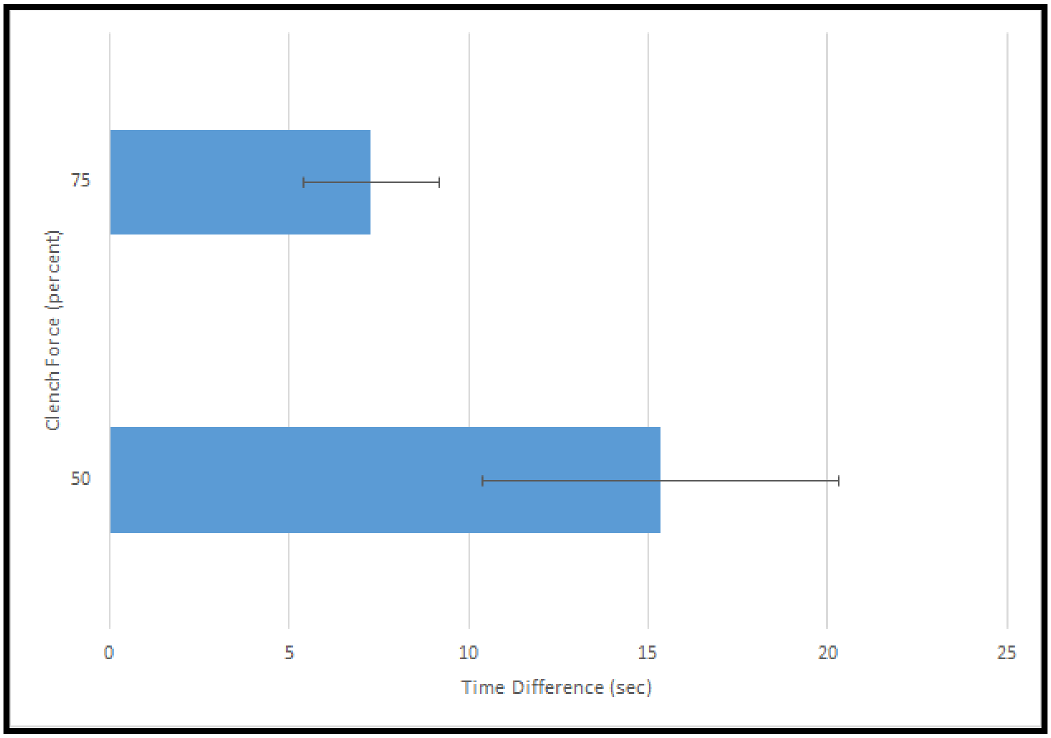


*Figure 18: Clench Force vs Time Difference for Non-Dominant Hand.* This figure shows the time difference to reach a clench force level from the previous level, 100% to 75% then 75% to 50%. The solid bar shows the average time difference, and the error bars show 95% confidence intervals.

**11. What relationship do you expect to see between clench force and integrated EMG over time duration of the fatigue test? Explain your answer.**

We expect to see the integrated EMG and the clench force both decrease over time. Since the subject is continuously clenching the device until they've dropped below 50%, their integrated EMG will also decrease. In previous sections, we saw the integrated EMG increase as the clench force increased, but since the clench force is decreasing due to fatigue, we would expect the integrated EMG to also decrease. This would mean there is a direct relationship between clench force and integrated EMG over time.

**12. Does the data from your group show this relationship from Q11? Include a graphic to help explain your answer. Hint: think about how to normalize this data. Also, is there a way to show this relationship with a single line per subject? How about a single line for all subjects in your group?**

To graph clench force vs integrated EMG, we first normalized the data by dividing by the greatest number in each dataset. For Participant 1 in our group, we divided all the Mean Force values by the greatest Mean Force. Similarly, we divided all the Mean Integrated EMG values by the greatest Mean Integrated EMG value. This same process was done for all four members. For this, dominant and non-dominant hand values were combined since the relationship between clench force and integrated EMG should be the same regardless of hand used. Plotting these normalized values gives a single line that shows a direct relationship between clench force and integrated EMG, as shown in the following figures.

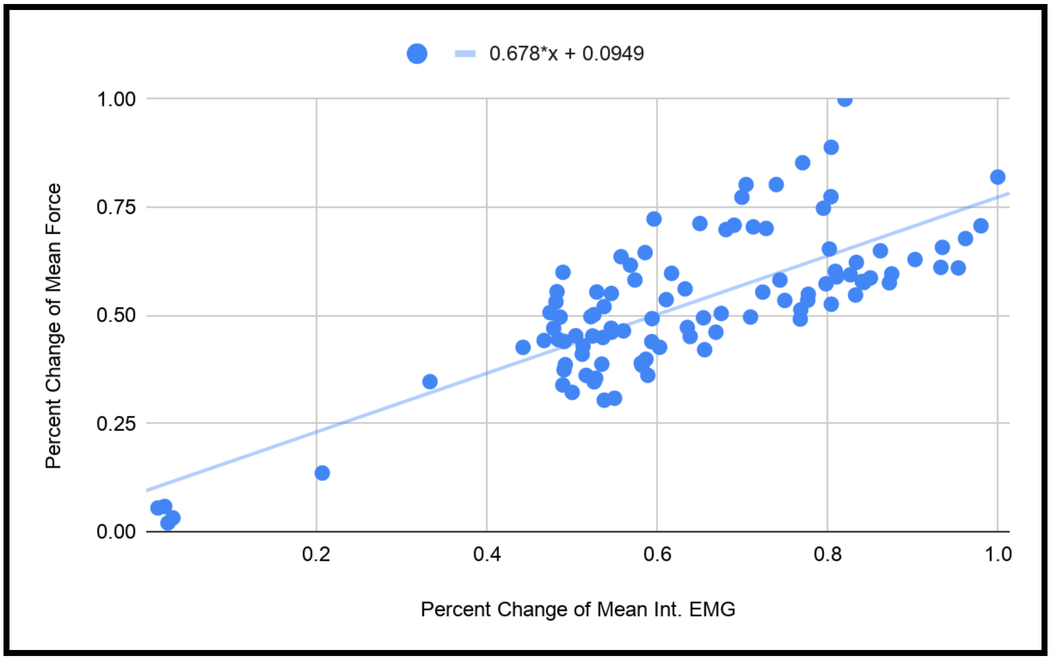


*Figure 19: Mean Force vs Mean Int. EMG for participant 1.* This shows the normalized clench force and integrated EMG values for participant 1 in group 0501.

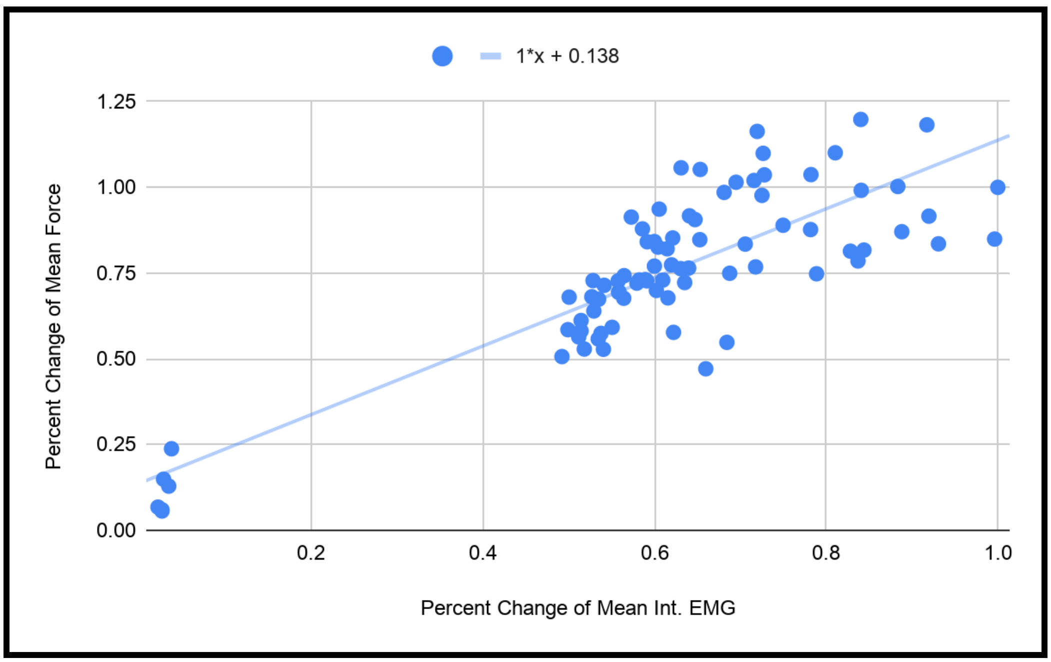


*Figure 20: Mean Force vs Mean Int. EMG for participant 2.* This shows the normalized clench force and integrated EMG values for participant 2 in group 0501.

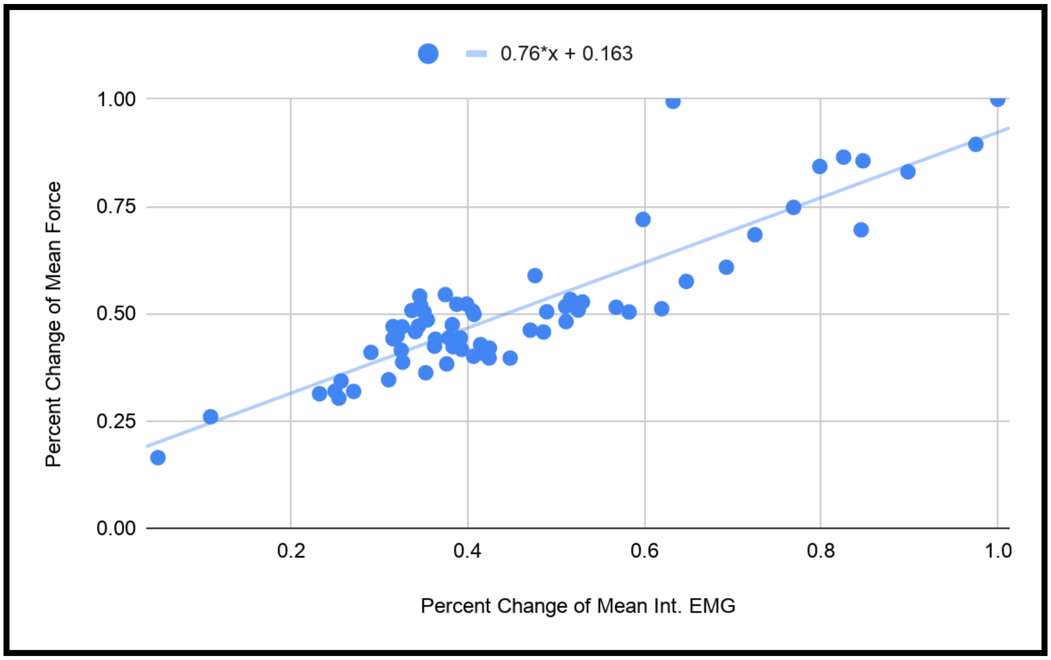


*Figure 21: Mean Force vs Mean Int. EMG for participant 3.* This shows the normalized clench force and integrated EMG values for participant 3 in group 0501.

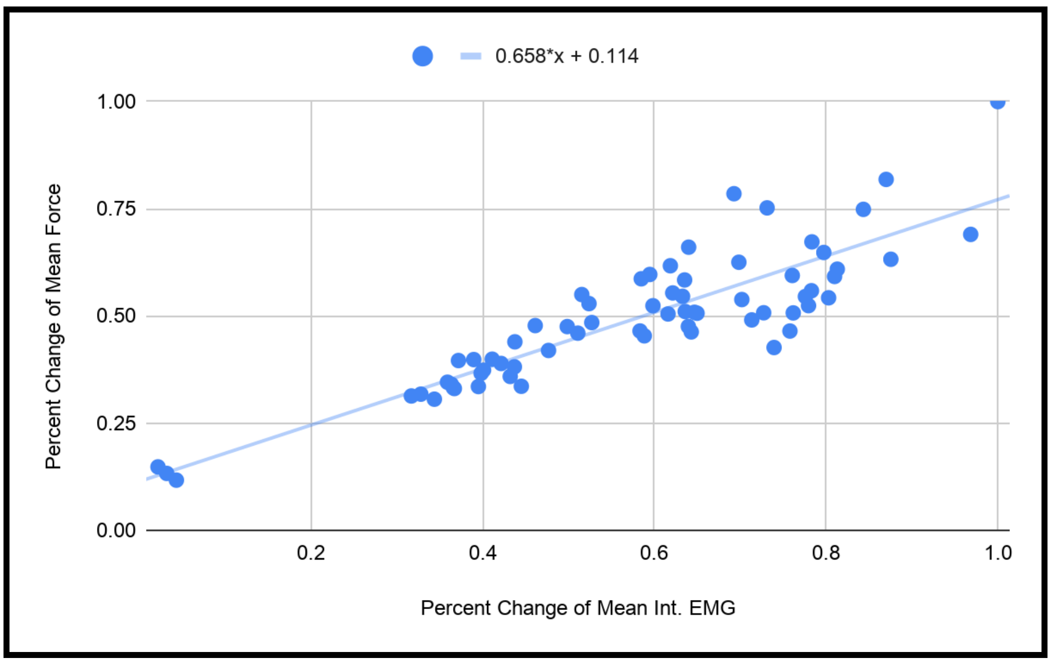


*Figure 22: Mean Force vs Mean Int. EMG for participant 4.* This shows the normalized clench force and integrated EMG values for participant 4 in group 0501.

We can also show this using a single line for our whole group if we normalize all the data using the greatest Mean Force and Mean Integrated EMG values for the entire group. The same normalization process as above was performed using the entire group data combined into one dataset. The created figure is shown below.

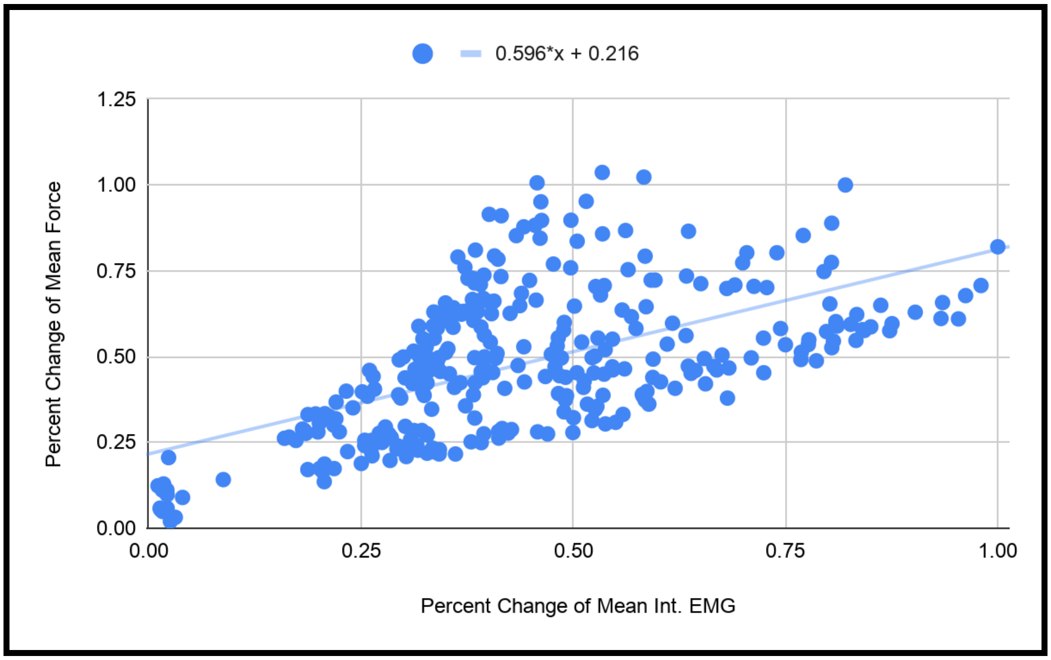


*Figure 23: Mean Force vs Mean Int. EMG for group 0501.* This shows the normalized clench force and integrated EMG values for all participants in group 0501.

**13. For this question, provide two graphs that show normalized data (see Question 4). Plot A is intended for a technical audience that is familiar with all concepts of muscles and EMG. Plot B is intended for a general audience of non-experts. Include a brief explanation of how the two plots are different and why.**

For our technical graph, we will revisit Figure 9 from Question 4.

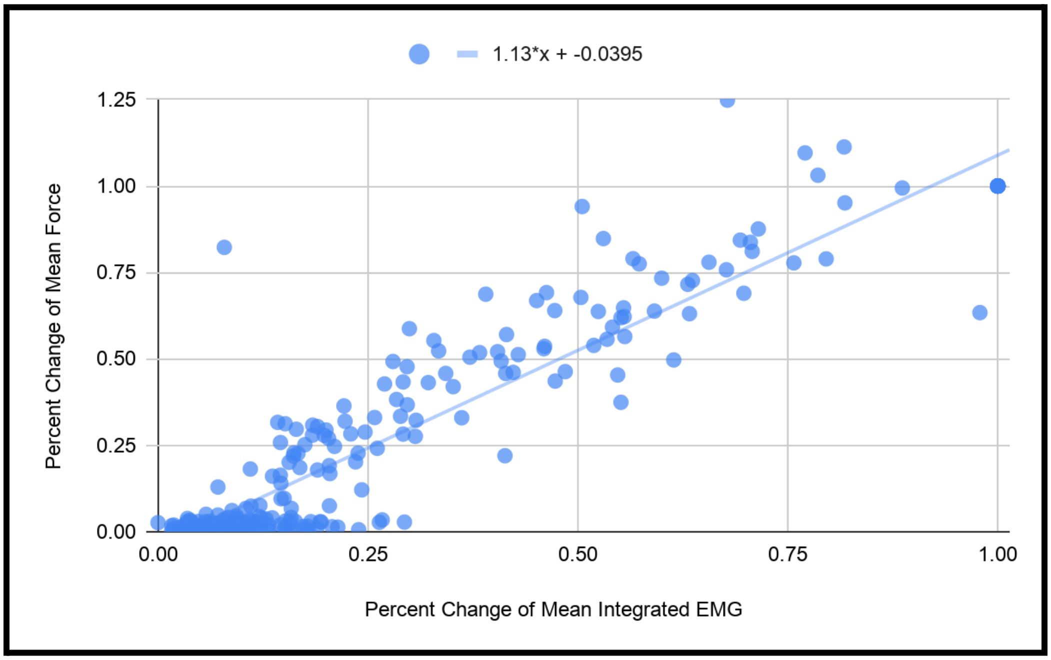


*Figure 24: Normalized scatter plot of dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV) data for all participants in section A, excluding two datasets with erroneous negative force values.*

For the graph intended for a more general audience, we simplified Figure 9. All the data points were removed so only the overall trend is shown. The axis titles were also changed to be easier to understand and the scale was changed to be from 0-100 instead of 0-1 in order to more simply represent a percentage. A non-expert audience would be less interested in specific data points and would instead only care about the general trend. Overall, the same trend is shown, but just in less specificity in Figure 25.

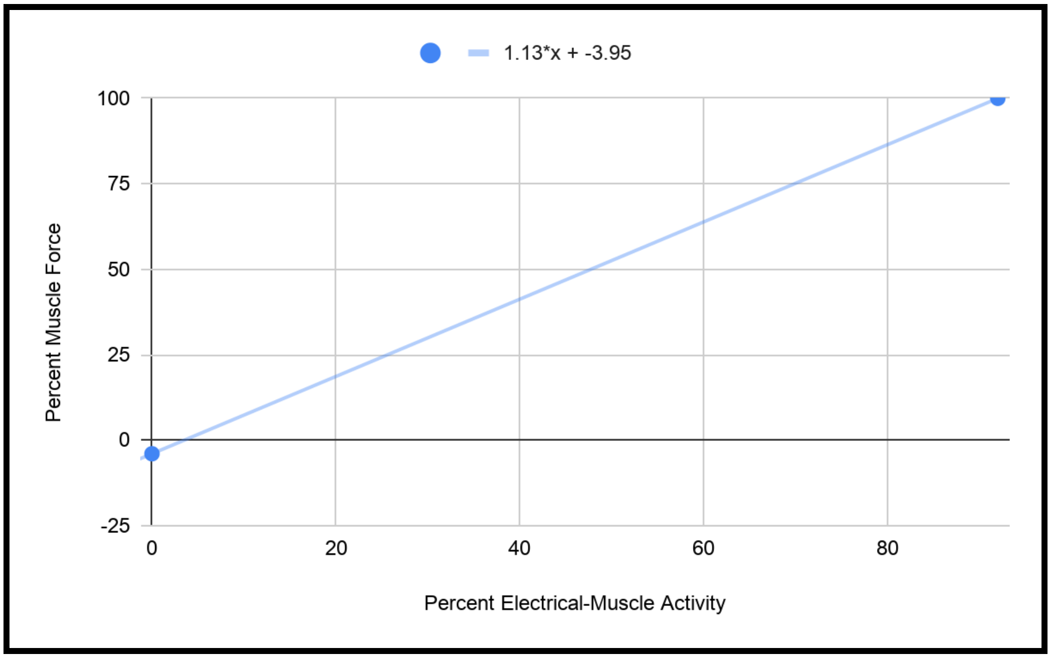


*Figure 25: Normalized scatter plot of dominant-handed Mean Force (Kg) vs. Mean Int. EMG (mV).* For all participants in section A, excluding two datasets with erroneous negative force values and simplified.

# Extra Credit

**14. Why is normalizing in question 4 by the maximum EMG force better than normalizing by the EMG and force during the 25% clench tests? In both cases, do you lose anything by normalizing?**

By normalizing the data in question 4 by the maximum EMG force, it gives us a better scale because we're using the largest value to determine the scale, meanwhile using the force for the 25% clench test will give us a much smaller scale. If we forced the data to fit a smaller scale, it would be harder to see overall patterns in the data.

**15. You have additional information about your subjects. How might one or more of these factors significantly impact EMG, force, and fatigue? Explain your answer, and use the data to determine if you are correct. All answers must include an evaluation of EMG, force, and fatigue and how they are connected. The quality of your logic, data analysis, and presentation will factor into your score. Answers without results will get no credit.**

We hypothesized that people who regularly exercise would have a stronger correlation between Mean Integrated EMG and Mean Force. To verify this, we used our normalized EMG and Force data and split up our data into four groups: those who exercise and their dominant/non dominant data, and those who do not exercise and their dominant/non dominant data.

We have some puzzling data when comparing those who exercise versus those who did not exercise. Participants who exercised and used their dominant hand had a stronger trendline between their EMG and Force data (1.04x) compared to their non-exercising counterparts (1.02x). This difference, however, is quite minimal. When it comes to the non-dominant-hand data, exercising participants actually had a lower slope (.94) compared to their non-exercising counterparts (1.07x). We would have expected the slope to be higher in the exercising participants due to stronger skeletal muscle and therefore less exertion needed per force exerted. However, the variation in slope could be explained by the difference in the number of datapoints between exercising and non-exercising participants, as there are nearly twice as many exercising participants compared to non-exercising participants.

Regarding fatigue data, ie. the fatigue tonus, post clench, and post clench tonus, we found similar trends as described previously. Dominant exercising participant data has a higher slope than non dominant counterparts (.878x vs. .795x) while non-exercising dominant participants had a lower slope than their non-dominant counterparts (.789x vs .819x)

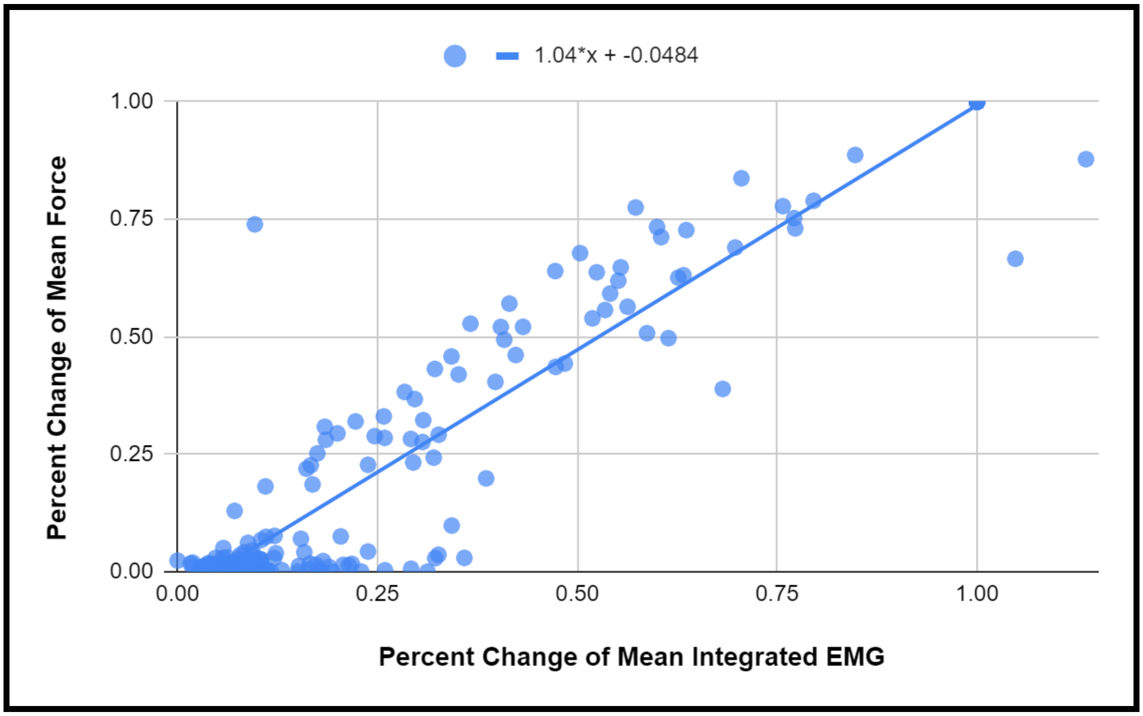


*Figure 26: Percent change of Mean Force vs Percent change of Mean Int. EMG in exercising participants' dominant-handed data during the short clench phase. Percent change is relative to each individual's maximum EMG/Force values*

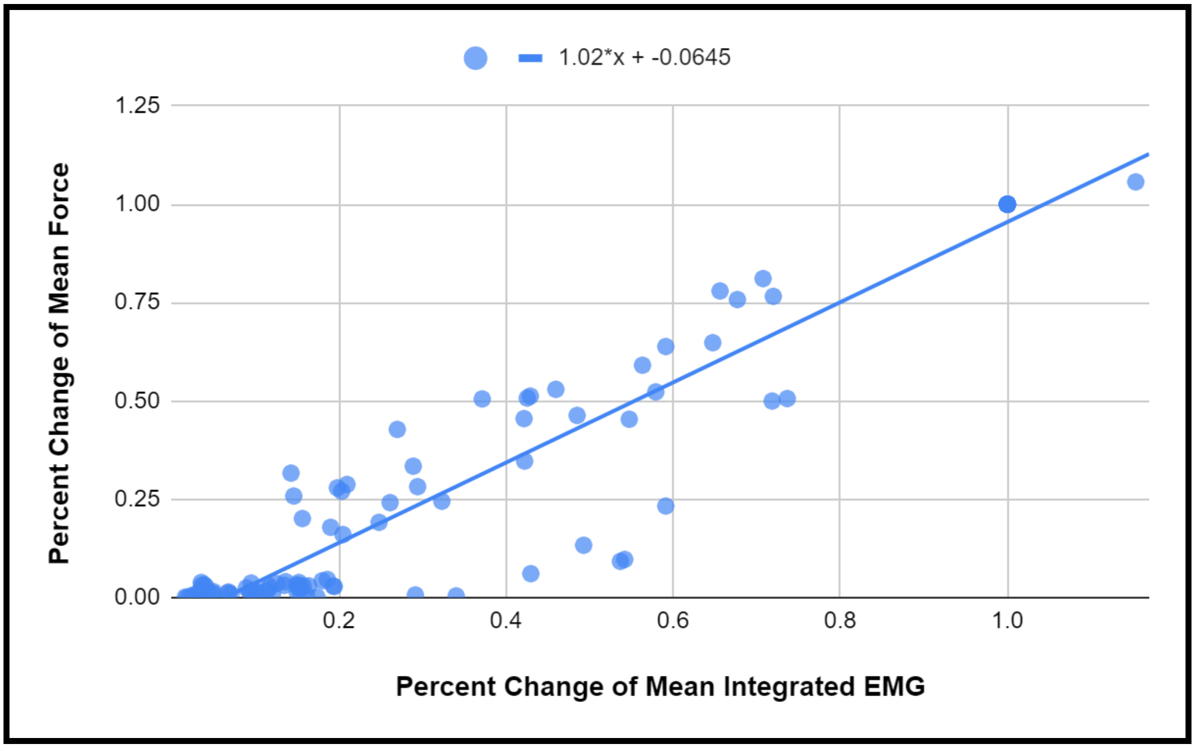


*Figure 27: Percent change of Mean Force vs Percent change of Mean Int. EMG in non-exercising participants' dominant-handed data during the short clench phase. Percent change is relative to each individual's maximum EMG/Force values*

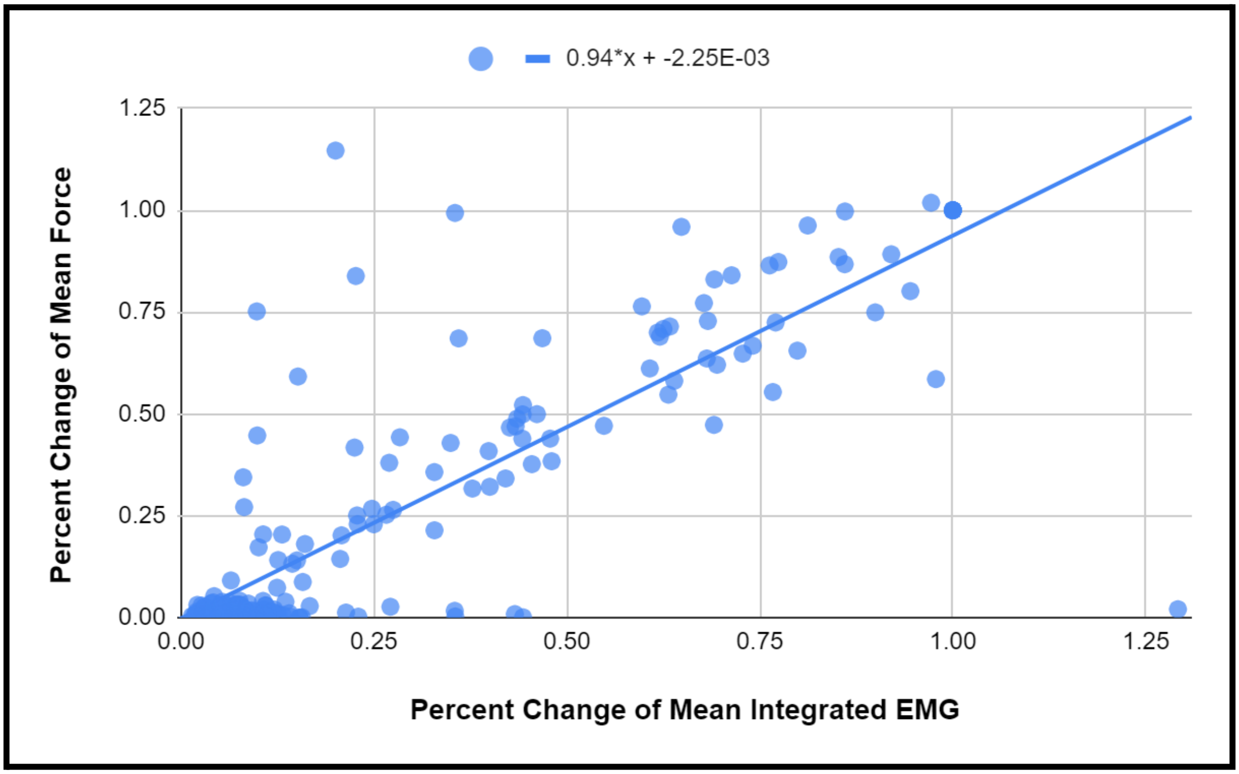


*Figure 28: Percent change of Mean Force vs Percent change of Mean Int. EMG in exercising participants' non-dominant-handed data during the short clench phase. Percent change is relative to each individual's maximum EMG/Force values*

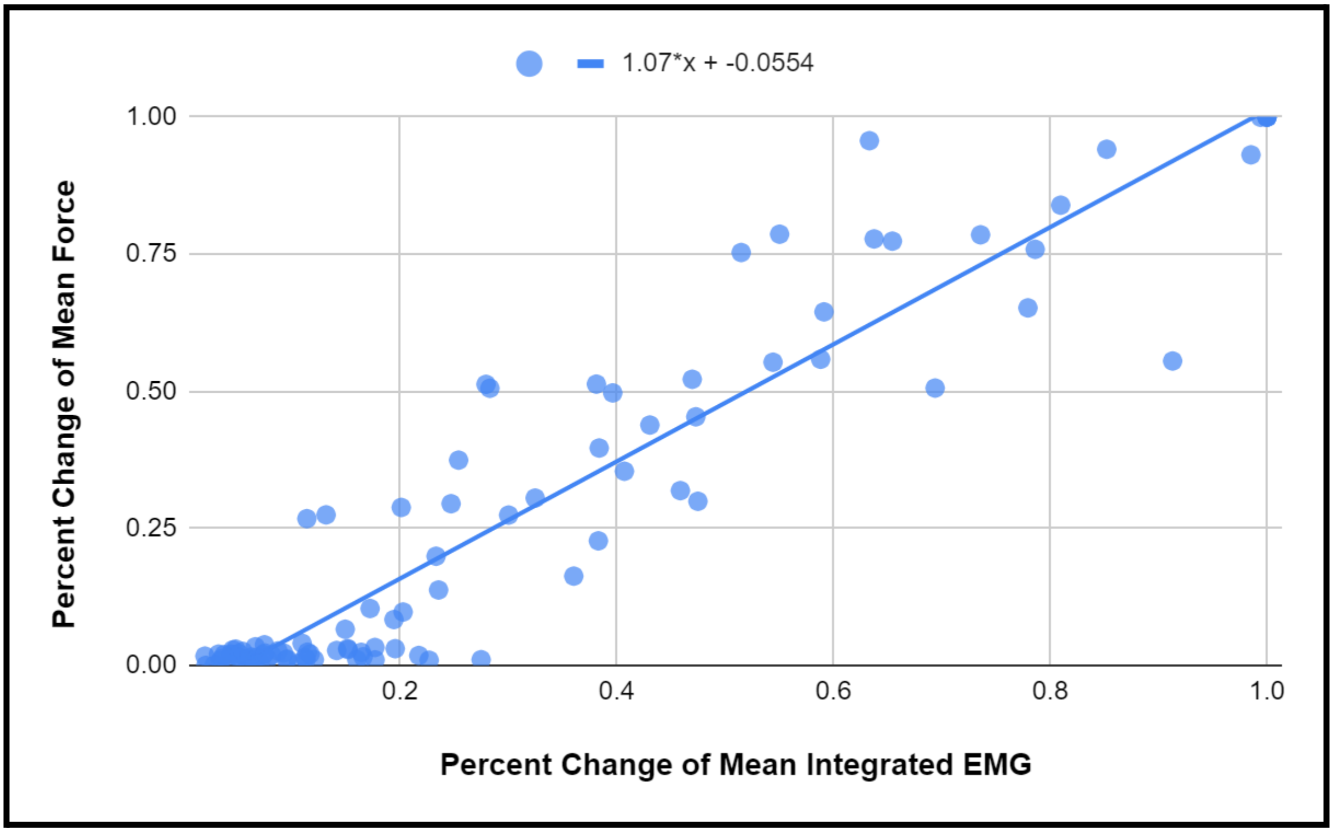


*Figure 29: Percent change of Mean Force vs Percent change of Mean Int. EMG in non-exercising participants' non-dominant-handed data during the short clench phase. Percent change is relative to each individual's maximum EMG/Force values.*

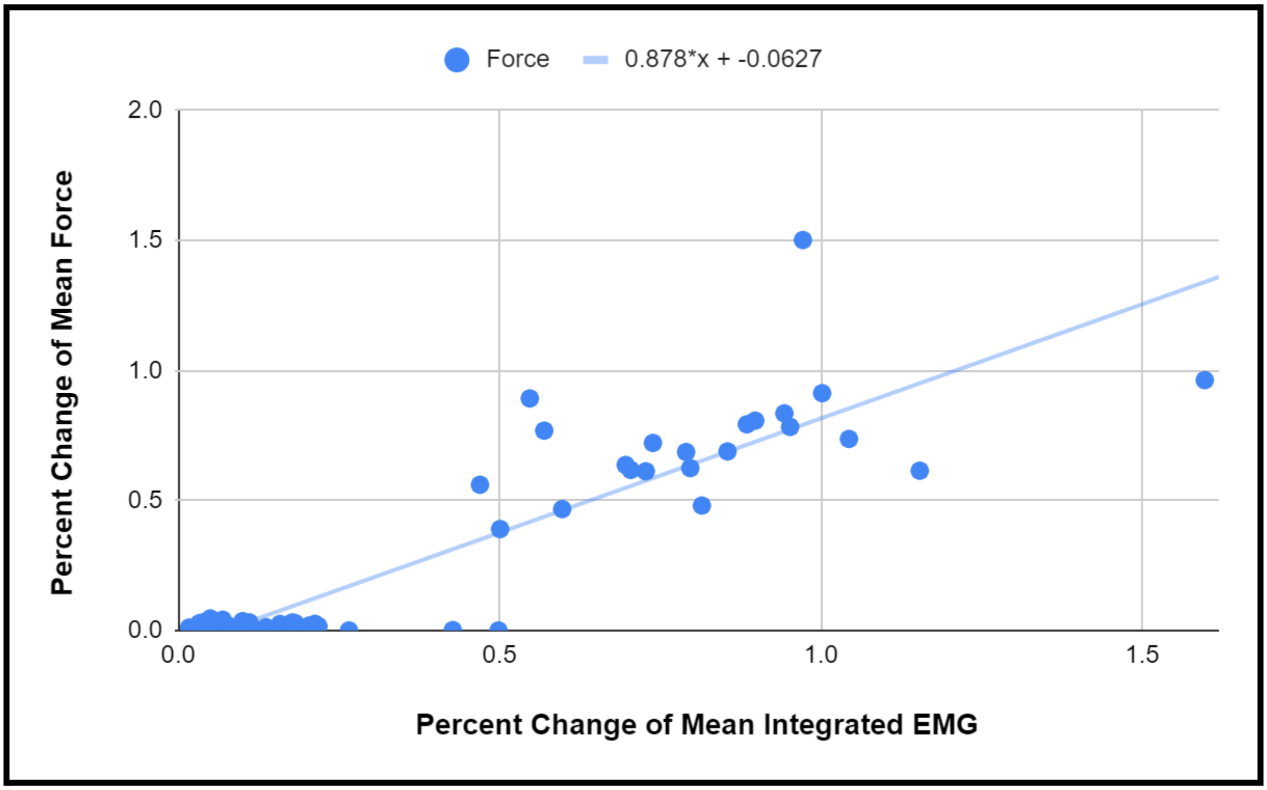


*Figure 30: Percent change of Mean Force vs Percent change of Mean Int. EMG in exercising participants' dominant-handed data during the fatigue. Percent change is relative to each individual's maximum EMG/Force values*

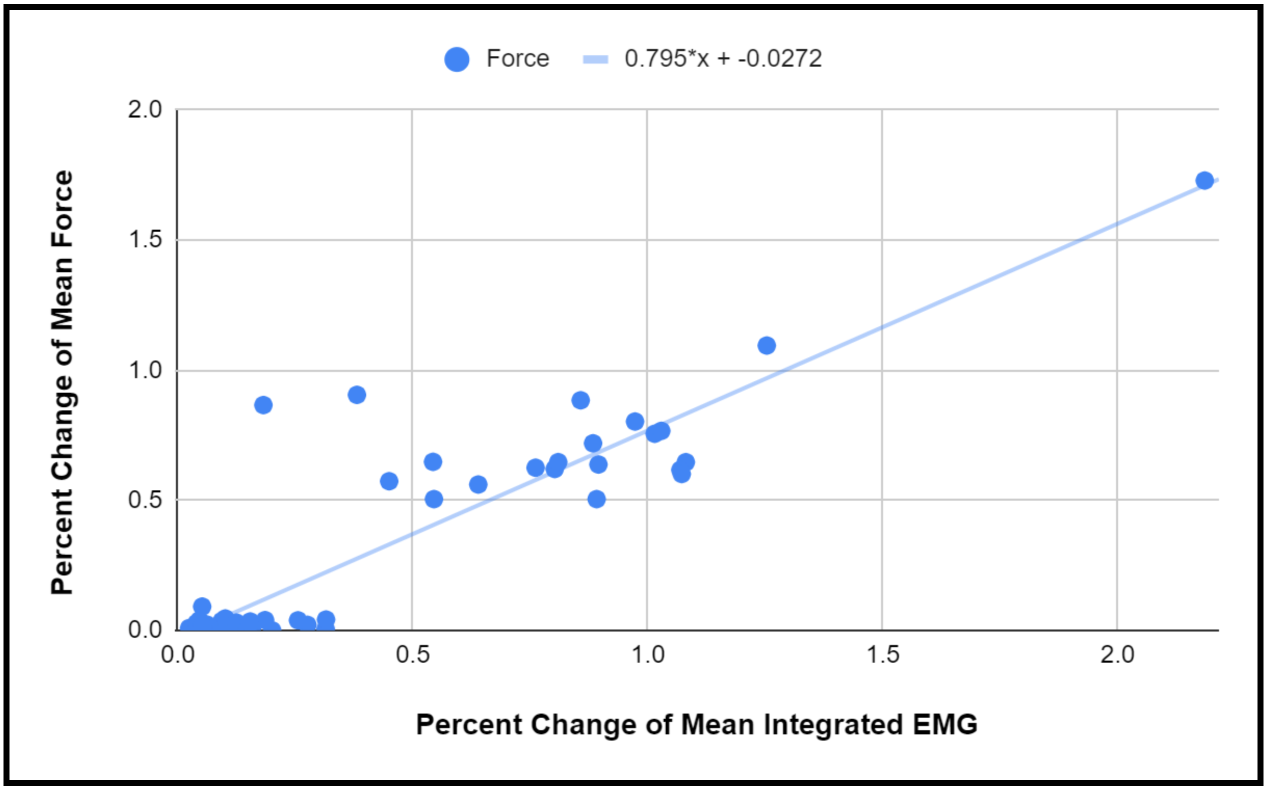


*Figure 31: Percent change of Mean Force vs Percent change of Mean Int. EMG in non-exercising participants' dominant-handed data during the fatigue phase. Percent change is relative to each individual's maximum EMG/Force values*

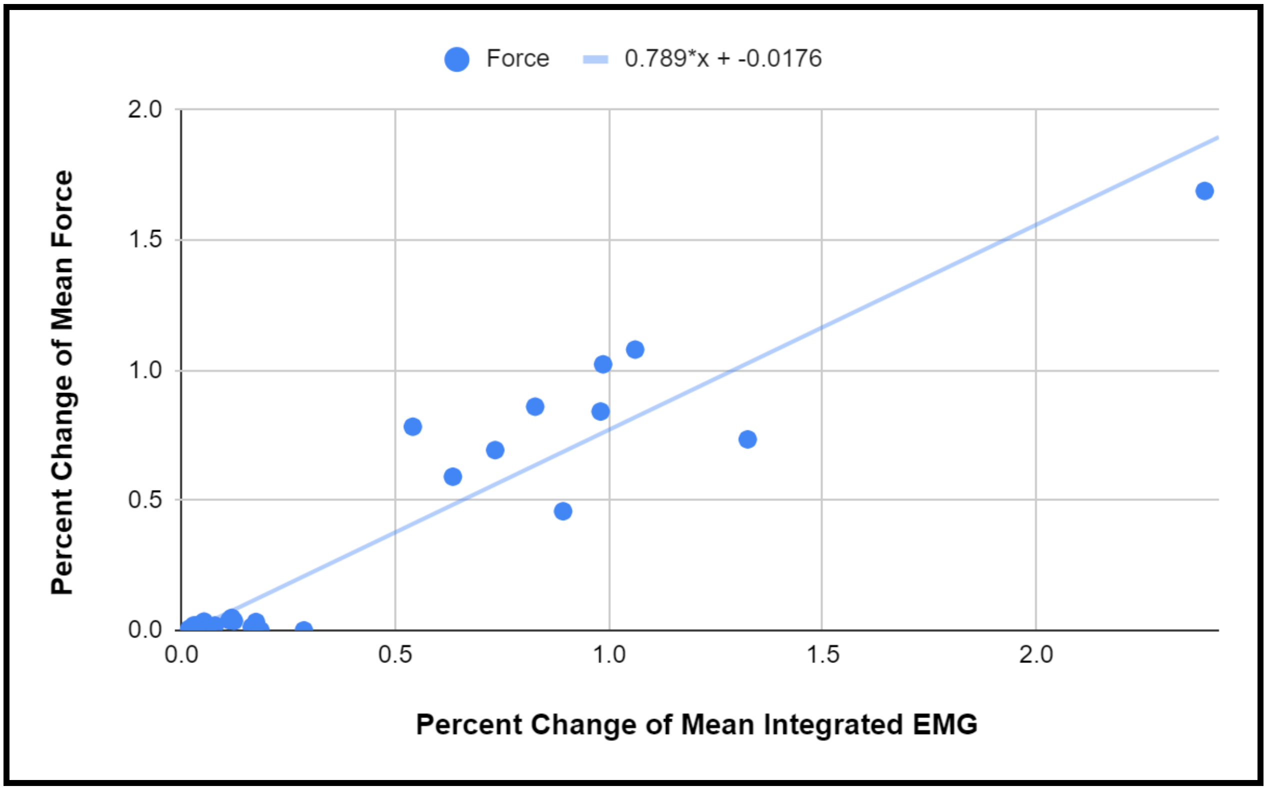


*Figure 32: Percent change of Mean Force vs Percent change of Mean Int. EMG in exercising participants' non-dominant-handed data during the short clench phase. Percent change is relative to each individual's maximum EMG/Force values*

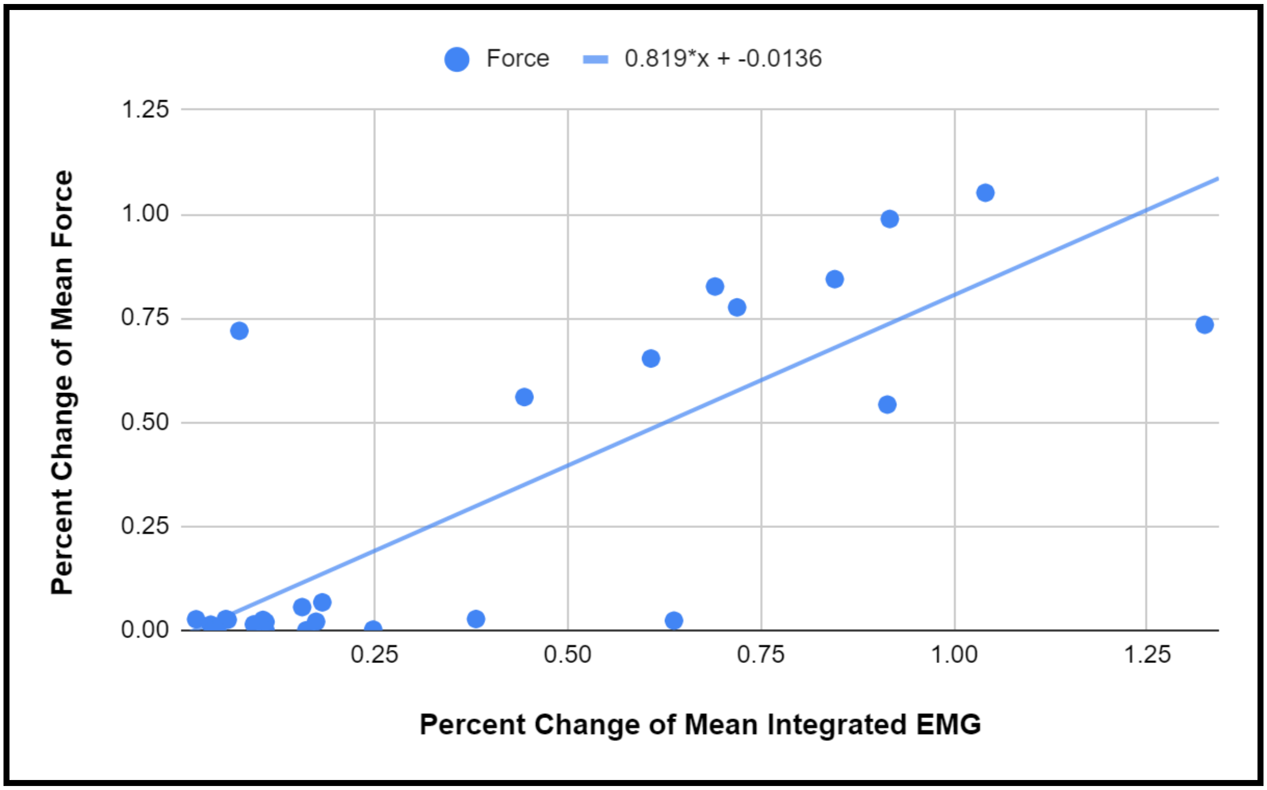


*Figure 33: Percent change of Mean Force vs Percent change of Mean Int. EMG in non-exercising participants' non-dominant-handed data during the short clench phase. Percent change is relative to each individual's maximum EMG/Force values.*