Lab #2: Introduction to Differential Amplifiers and Designing an Amplifier for EMG

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Name	Student #	Lab Contribution
Sophie Mansfield	400178392	Summary of the design + answers for questions A3 and B5
Lauren Stephens	400270259	Answers for questions C10, C11, and C12
Jiaqi Du	400249700	Answers for questions C7, C8, and C9

Summary of Our Design

Figure 1 below shows the circuit schematic utilized for this laboratory investigation, consisting of three main stages. In the initial headstage, the input signal is amplified, resulting in a gain equal to 50. Next, the signal is passed through a high-pass filter with a cut-off frequency of 10Hz. This means that signals below 10Hz (e.g., instrumentation noise) are attenuated, while those above 10Hz are passed. The signal is then amplified again, with a stage gain of 20. Finally, the signal is passed through a low-pass filter with a cut-off frequency of 500Hz. In this case, signals above 500Hz are attenuated, while those below 500Hz are passed. This results in a circuit that is suitable for EMG measurements.

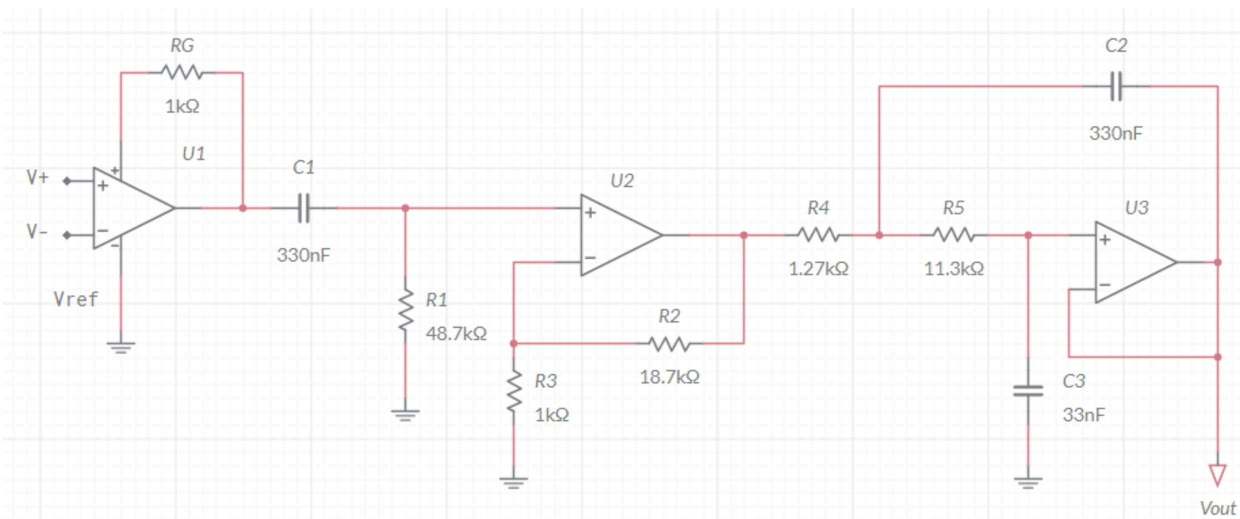


Figure 1. Circuit schematic, including the headstage, high-pass filter, and low pass filter stages.

Part A: Measuring the CMRR of the Headstage Differential Amplifier

Question A3. *Calculate common mode gain, CMRR, CMR (dB).*

$\Delta Y(1) = +52mV$ (from the oscilloscope)

$$G_{CM} = \frac{V_{out_{CM}}}{V_{in_{CM}}} = \frac{52\ X\ 10^{-3}\ V}{3V} = 0.0173$$

$$CMMR = \frac{G_{Diff}}{G_{CM}} = \frac{50}{0.0173} = 2884.62$$

$$CMR = 20\log(CMMR) = 69.20\ dB$$

The results from the above calculations are summarized in Table 1 below. Although CMR is mathematically unitless, the value is reported in units of dB.

Table 1. Headstage differential amplifier characteristics

Common Mode Gain, G_{CM}	CMMR	CMR (dB)
0.0173	2884.62	69.20

Part B: Building Circuit and Checking Gain Frequency Response

Question B5. *Plot gain vs. frequency. Explain the shape of the gain vs frequency plot and how it relates to filter stages in the circuit design.*

The response of the circuit to different frequencies is summarized below in Table 2. It was confirmed that the input voltage was approximately 10mV for all frequencies, although it should be noted that this may be slightly off due to instrumentation noise.

Table 2. Circuit output voltages and gain values calculated for different input frequencies

$Frequency\ (Hz)$	$V_{in}(mV\ p-p)$	$V_{out}(mV\ p-p)$	$G = V_{out}/V_{in}$
1	10	123	12.3
10	10	434	43.4
50	10	579	57.9
100	10	595	59.5
200	10	627	62.7
300	10	635	63.5
400	10	547	54.7
500	10	430	43.0
600	10	321	32.1
1000	10	157	15.7
1500	10	102	10.2
2000	10	82	8.20

From Table 2, a plot of frequency vs. gain could be plotted. This graph is shown below in Figure 2.

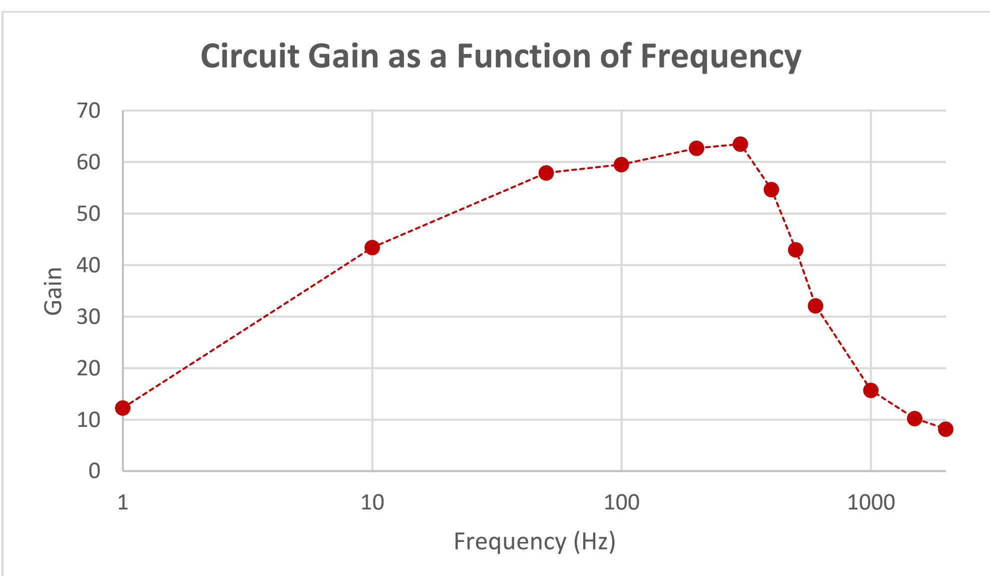
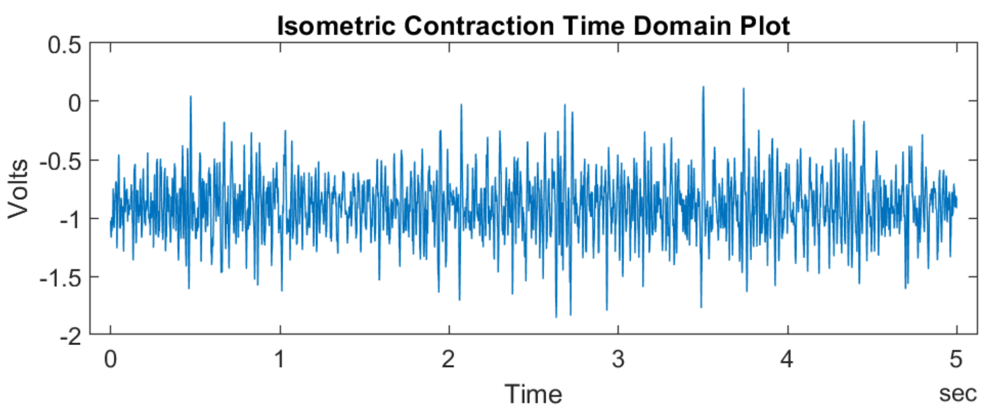


Figure 2. Circuit gain as a function of frequency (semi-log plot).

As seen in Figure 2, the gain response follows a nearly parabolic curve – the gain increases up to a certain peak (corresponding to a frequency of 300Hz) before decreasing. It should be noted that frequency has been plotted on a logarithmic scale, so there is realistically only a slight decrease for frequency values from 1000 to 2000 Hz. The frequency response of the circuit allows us to see how the output gain (magnitude response) changes over a range of frequencies. Knowing the values of the circuits gain at each frequency helps us understand how well the circuit can distinguish between signals of different frequencies. Around frequencies of 10Hz, we see the effect of the initial high-pass filter, wherein signals below the cut-off frequency (10Hz) are being attenuated, while those above are being passed and then amplified. Between 10 Hz and 500 Hz, the signal gain is fairly consistent; the maximum outputs are exhibited in this range (the bandwidth). Above 500Hz, the low-pass filter acts to attenuate signals above the cut-off frequency, as we can see by the negative slope in this region of the curve.

Part C: Acquiring an EMG Signal

Question C7. *Time domain and frequency domain plot for an isometric contraction (i.e., the EMG signal vs time and the Fourier Transform from 0 to 500Hz)*



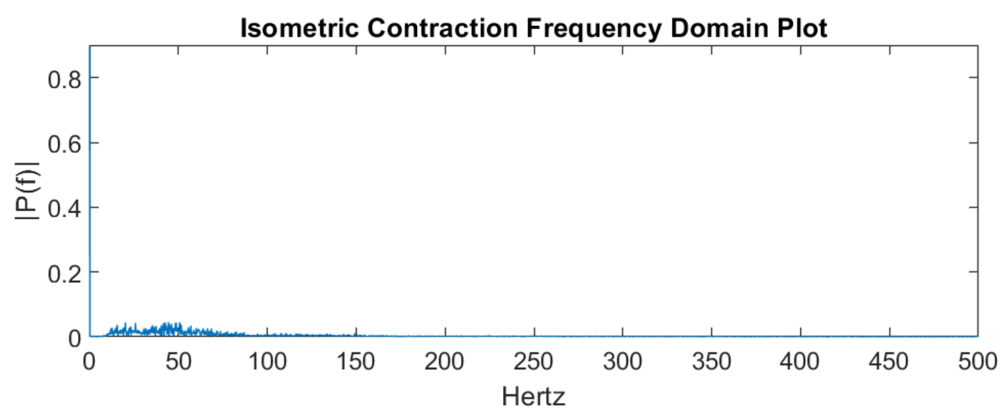


Figure 3. The time domain (top) and frequency domain (bottom) plots from 0-500Hz of the EMG signal recording one constant isometric contraction in the right bicep. Due to noise, the time domain signal appears to have multiple peaks, even though there should be no shape detected with constant muscle activity. There is an unexpected peak at 0Hz in the frequency domain, which can be attributed to the negative offset in the original signal. The zoomed in graph on the signal will be shown later in the report.

Question C8. *Time domain raw and enveloped data plots (using a 2Hz low pass filter) and then frequency domain plot for the raw slow dynamic contractions*

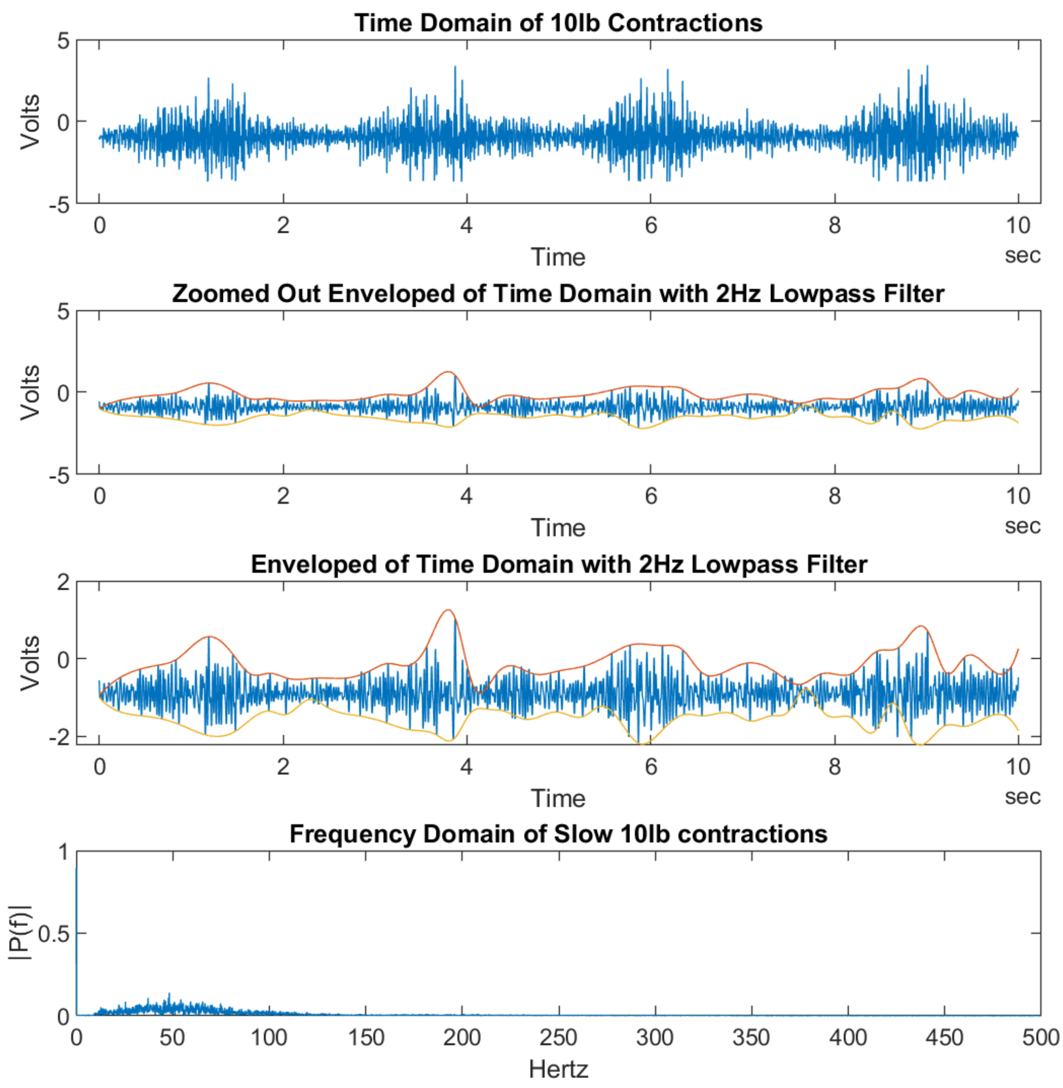


Figure 4. The raw and filtered and enveloped time domain graphs, as well as the frequency domain from 0-500Hz of EMG signals of slow 10lb contractions in the biceps. In the unfiltered graph (top), the occurrence of each contraction can be clearly seen. It seems like, however, that

the higher frequencies helped to increase the voltage of each contraction, since with a 2Hz lowpass filter, the curves of the time domain were muted and not as apparent, making it more difficult for the envelope to show the sine wave shape that should be seen.

Question C9. *Time domain raw and enveloped data plots (using a 2Hz low pass filter first and then a 10 Hz LPF) and the frequency domain plot for the raw fast contractions.*

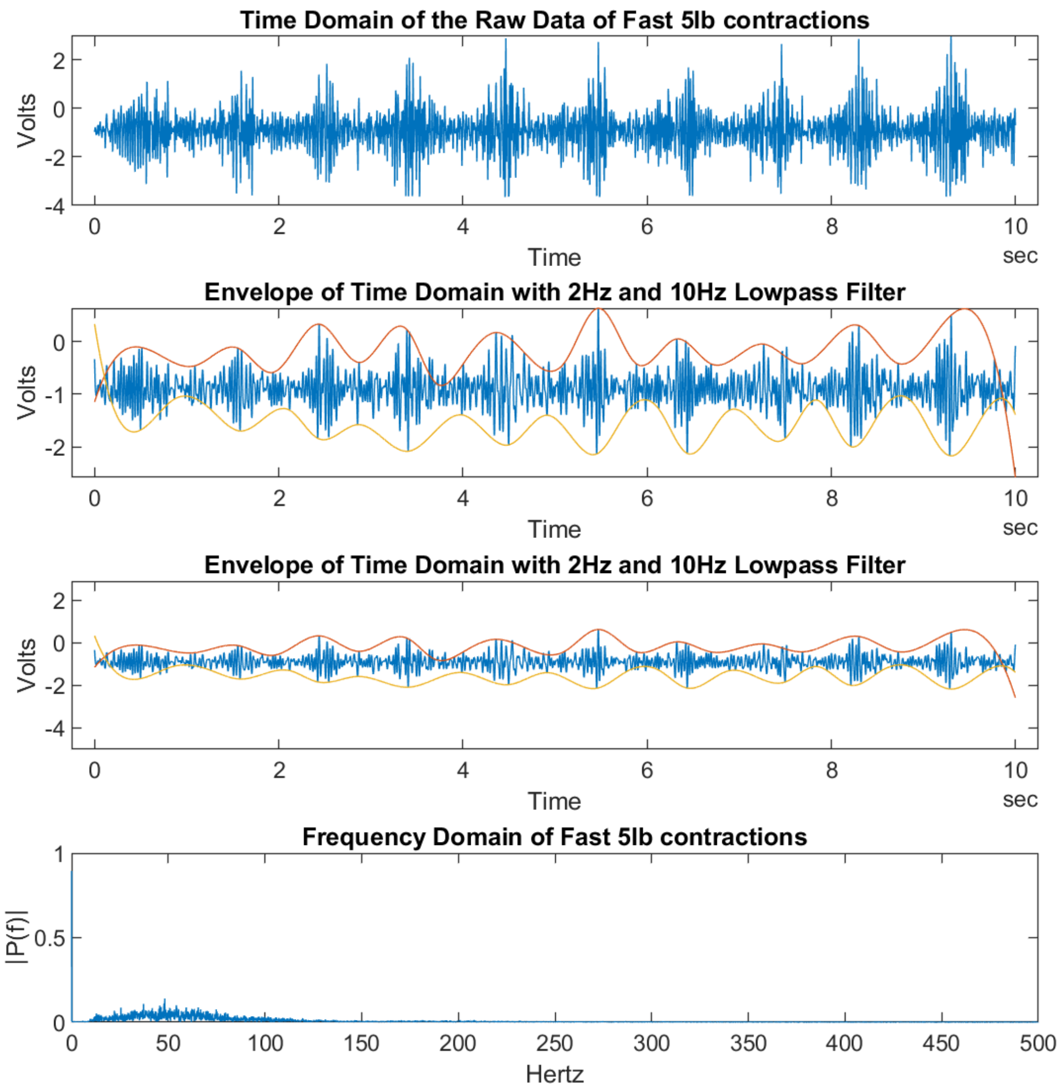


Figure 5. The raw and filtered enveloped time domain, as well as the frequency domain of fast 5lb contractions. The envelope clearly shows a sine wave-like pattern, which shows every contraction done by the bicep during measurement. The envelope may be clearer that the previous figure since there may be a more well-defined peak of muscle activity during a fast contraction compared to a slow contraction, leading to clearer curves. Theoretically, the 10Hz lowpass filter should have no effect on the final graph, since a 2Hz lowpass filter would have

attenuated anything above its cutoff, including 2-10Hz frequencies that wouldn't have been attenuated with a 10Hz lowpass filter.

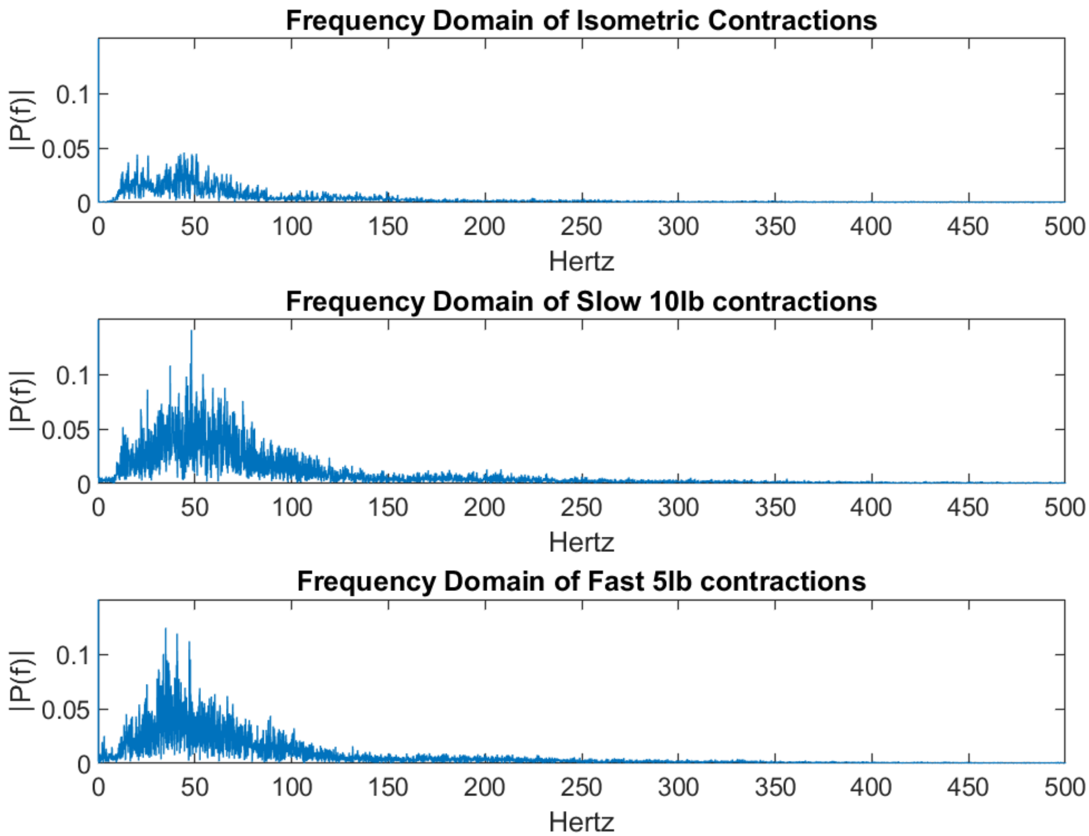


Figure 6: In all three graphs, there is increased activity from the 10-100Hz range. The overall magnitude seems to increase with more weight contracted, therefore the lowest overall frequency magnitude is seen in the constant isometric contraction, and the highest can be seen in the slow 10lb contractions. The frequency domain of isometric contractions show no noticeable peak in frequency, which may be due to the EMG recording a constant muscle activity, with low amounts of peaks in the time domain signal. In the slow 10lb contractions, there is a noticeable peak around 50Hz, and in the fast 5lb contractions, the strongest frequency domain is around 40Hz. This may be due to the difference of fast and slow contractions.

Question C10. *For each 3 second recording, first remove the DC offset from the signal, then rectify each section (abs value) and then compute the average magnitude. Then, plot average magnitude vs. weight (should have 5 points to plot).*

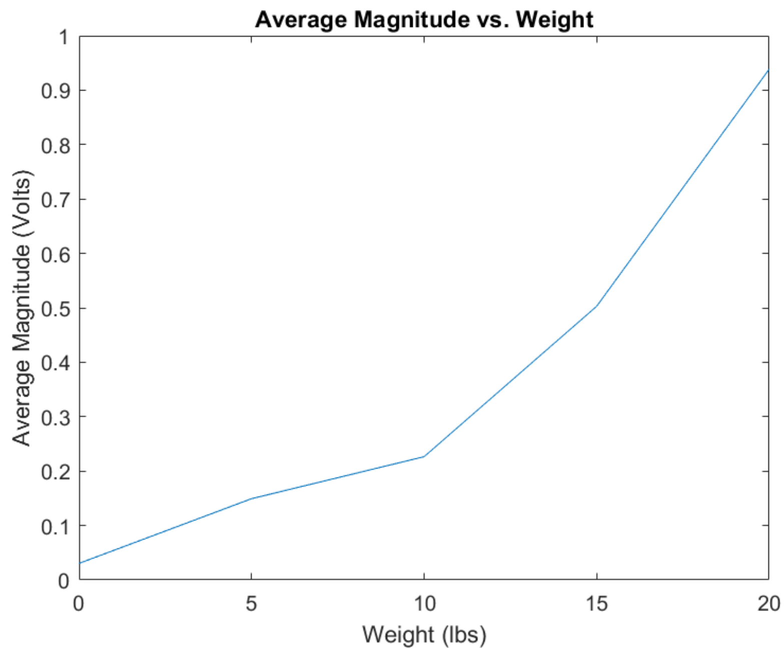


Figure 7: The average magnitude vs. weight graph shows a positive exponential relationship, which is as expected. As the muscle tries to support more weight, there will be more electrical activity within the muscle, which produces these results.

Question C11. *Break the minute of data into 10 second intervals. Compute the RMS and centroid frequency (MATLAB function) value for each interval and plot over time. Describe any changes you see.*

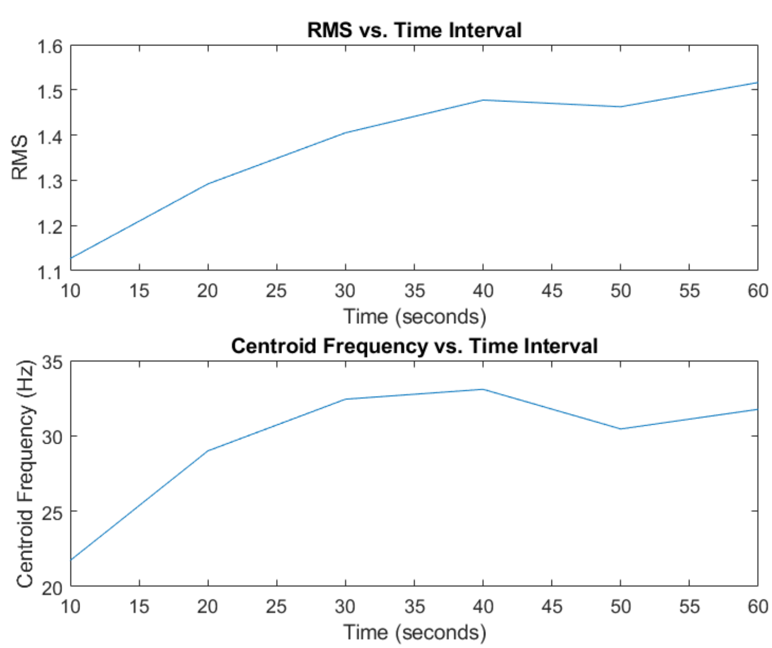


Figure 8: The first graph shows the plot of RMS values vs. time. It is seen that the RMS increases in a linear manner until about 40 seconds, after which it becomes more constant around 1.5. RMS represents the power of the signal over time, so it is expected that as the muscle fatigues, it must expend more power to hold the weight. The second graph shows the plot of centroid frequency vs. time. It is seen that this also increases with time until about 40 seconds, and then becomes more constant around 30-35 Hz. Comparing the two graphs, they have a similar shape. In the RMS graph, the first 40 seconds are very linear, and the peak value doesn't occur until the last interval. In the centroid frequency graph, the first 40 seconds are increasing in a logarithmic fashion, with the peak happening closer to the middle of the time duration.

Question C12. *Explain why twisting the electrode leads (wires) reduces 60Hz noise in the signal.*

Twisting the electrode leads reduces 60Hz noise in the signal, which is produced by power-line interference. This is due to untwisted wires making a closed loop with the patient that has a large surface area. Changes in magnetic field within this loop can induce a current via Faraday's Law of Induction. By twisting the wires, this closed loop has a smaller inductive area, which leads to less 60Hz noise.

Appendix:

```
clc;
clear all;
close all;

%plot time domain of C7
load('C7.mat');
subplot(2,1,1);
plot(C7,'Dev6_ai0');
title('Isometric Contraction Time Domain Plot')
ylabel('Volts');

%plot frequency domain using fourier
%c7 = timetable2table(C7);
Fs = 1000 ;  %sampling freq
T = 1/Fs;    %sampling time
StopTime = 5; %time in seconds
t = (0:T:StopTime-T);
%L = 5000 ;   %sampling length
L = size(t,2);

x = fft(C7.Dev6_ai0);   %fourier transform the signal
f = Fs*(0:(L/2))/L;        %create x-axis

%dF = Fs/L;
%f = -Fs/2:dF:Fs/2-dF;
p2 = abs(x)/L;      %calculate the 2 sided spectrum
p1 = p2(1:L/2+1);   %calculate the 1 sided sprectrum
p1(2:end-1)= 2*p1(2:end-1);
%fl = linspace(0,500,L);
subplot(2,1,2);
```

```
plot(f,p1);
xlabel('Hertz');
ylabel('|P(f)|');
ylim([0,0.9]);
title('Isometric Contraction Frequency Domain Plot');

%%
load('C8.mat');

T_8 = 0.001;     %sampling rate
Fs_8 = 1/T_8;    %sampling freq
StopT_8 = 10;    %total time measured
t_8 = (0:T_8:StopT_8-T_8);  %table incrementing by time in C8
L_8 = size(t_8,2);  %determine number of samples in 10s
f_8 = Fs_8*(0:(L_8/2))/L_8;         %create x-axis

C8_pass = lowpass(C8, 2);
x_8 = fft(C8.Dev6_ai0); %Fourier transform
p2_8 = abs(x_8)/L_8;    %calculate 2 sided spectrum
p1_8 = p2_8(1:L_8/2+1);    %calculate the 1 sided sprectrum
p1_8(2:end-1)= 2*p1_8(2:end-1);

C8_pass = lowpass(C8, 2);  %lowpass filter of C8 set to 2 hertz

%find envelope:
c8 = timetable2table(C8_pass);
[up,low]= envelope(c8.Dev6_ai0,180,'peak');
figure;
subplot(4,1,1);
plot(C8,"Dev6_ai0");
ylabel('Volts');
title('Time Domain of 10lb Contractions');

subplot(4,1,2);
plot(C8_pass,'Dev6_ai0');
hold on
ylabel('Volts');
title('Zoomed Out Enveloped of Time Domain with 2Hz Lowpass Filter');
plot(t_8,up,t_8,low);
ylim([-5,5]);
hold off

subplot(4,1,3);
plot(C8_pass,'Dev6_ai0');
hold on
ylabel('Volts');
title('Enveloped of Time Domain with 2Hz Lowpass Filter');
plot(t_8,up,t_8,low);
hold off
subplot(4,1,4);
plot(f_8, p1_8);         %plot fourier transform
title('Frequency Domain of Slow 10lb contractions');
ylabel('|P(f)|');
xlabel('Hertz');

%%
```

```
load('C9.mat');

T_9 = 0.001;    %sampling rate
Fs_9 = 1/T_9;   %sampling freq
StopT_9 = 10;   %total time measured
t_9 = (0:T_9:StopT_9-T_9);  %table incrementing by time in C8
L_9 = size(t_9,2);  %determine number of samples in 10s
dF_9 = Fs_9/L_9;    %create X axis values for plot
f_9 = Fs_9*(0:(L_9/2))/L_9;        %create x-axis

C9_pass2 = lowpass(C9, 2);  %lowpass filter of C9 set to 2 hertz

%figure;
%plot(C9_pass2,'Dev6_ai0');
%title('2Hz only')

C9_pass = lowpass(C9_pass2, 10);  %lowpass filter of C9 set to 10 hertz
c9 = timetable2table(C9_pass);
[up9,low9]= envelope(c9.Dev6_ai0,300,'peak');

x_9 = fft(C9.Dev6_ai0);
p2_9 = abs(x_9)/L_9;
p1_9 = p2_9(1:L_9/2+1);   %calculate the 1 sided sprectrum
p1_9(2:end-1)= 2*p1_9(2:end-1);

figure;
subplot(4,1,1);
plot(C9,"Dev6_ai0");
title("Time Domain of the Raw Data of Fast 5lb contractions");
ylabel('Volts');

subplot(4,1,2);
plot(C9_pass,'Dev6_ai0');
title('Time domain of 5lb contractions with 2Hz and 10Hz Lowpass Filter')
ylabel('Volts')

hold on
title('Envelope of Time Domain with 2Hz and 10Hz Lowpass Filter');
plot(t_9,up9,t_9,low9);
hold off

subplot(4,1,3);
plot(C9_pass,'Dev6_ai0');
title('Zoomed out Time domain of 5lb contractions with 2Hz and 10Hz Lowpass
Filter')
ylabel('Volts')

hold on
title('Envelope of Time Domain with 2Hz and 10Hz Lowpass Filter');
plot(t_9,up9,t_9,low9);
%ylim([-2.2,0.65]);
ylim([-5,2.9]);
hold off

subplot(4,1,4);
plot(f_9, p1_9);        %plot fourier transform
title('Frequency Domain of Fast 5lb contractions');
```

```
ylabel('|P(f)|');
xlabel('Hertz');


%%
%plot multiple figure

figure;
subplot(3,1,1);
plot(f,p1);
ylim([0,0.15]);
ylabel('|P(f)|');
xlabel('Hertz');
title('Frequency Domain of Isometric Contractions');

subplot(3,1,2);
plot(f_8,p1_8);
ylim([0,0.15]);
ylabel('|P(f)|');
xlabel('Hertz');
title('Frequency Domain of Slow 10lb contractions');

subplot(3,1,3);
plot(f_9,p1_9);
ylim([0,0.15]);
ylabel('|P(f)|');
xlabel('Hertz');
title('Frequency Domain of Fast 5lb contractions');

%%C10

clear;
close all;

load('C10_0.mat');
load('C10_5.mat');
load('C10_10.mat');
load('C10_15.mat');
load('C10_20.mat');

data = {[C10_0.Dev6_ai0], [C10_5.Dev6_ai0], [C10_10.Dev6_ai0],
[C10_15.Dev6_ai0], [C10_20.Dev6_ai0]};
avg_magnitude = [];
x = [0, 5, 10, 15, 20];

for i = 1:length(data)
    offset = cell2mat(data(i)) - mean(cell2mat(data(i)));
    absolute = abs(offset);
    average = mean(absolute);
    avg_magnitude(end+1) = average;
end

plot(x, avg_magnitude);
title('Average Magnitude vs. Weight')
xlabel('Weight (lbs)');
ylabel('Average Magnitude (Volts)');
```

```
%% C11
clear;
close all;

load('C11_15.mat');

rms_array = [];
centroid_freq = [];
time=[10, 20, 30, 40, 50, 60];

for i=1:6
    rms_value = rms(C11_15.Dev6_ai0(((i-1)*10000 + 1):i*10000));
    rms_array(end+1) = rms_value;

    timetable = C11_15((((i-1)*10000 + 1):i*10000),:);
    array = table2array(timetable);

    centroid = spectralCentroid(array, 1000);
    centroid_freq(end+1) = mean(centroid);
end

subplot(2,1,1);
plot(time, rms_array);
title('RMS vs. Time Interval')
xlabel('Time (seconds)');
ylabel('RMS');

subplot(2,1,2);
plot(time, centroid_freq);
title('Centroid Frequency vs. Time Interval')
xlabel('Time (seconds)');
ylabel('Centroid Frequency');
```