

The Creation and Use of an EMG

Elizabeth Shimei

Abstract: The purpose of this experiment was to build a functioning electromyography (EMG) machine and to use it to test various properties of the muscle. Originally the hypothesis was that the gluteus maximus contributes equally to the movement of the fencing lunge as the quadriceps muscles do. This hypothesis was not able to be tested and instead preliminary experiments and underdeveloped hypothesis were examined in the last few days. The dominant period of time was spent fine tuning the EMG set up to take accurate measurements.

Introduction: In order to contract, muscles require signals from the brain. This is done in the form of neurons firing action potentials. An action potential is a wave of current that (usually) depolarizes a membrane in order to trigger a response. In the dendrites of a somatic motor neuron, this would be the release of acetylcholine (Ach). This triggers an action potential in the muscle fibers that the neuron innervates. This depolarization along the membrane of the muscle fiber moves in both directions so that the entire fiber is signaled to react simultaneously. The action potential results in a release of calcium ions within the cell, which then allows for actin-myosin crossbinding. This crossbinding and resulting contractions (by the myosin and actin heads sliding along one another) is what causes the muscle to shorten, producing force. Various aspects of the muscle physiology as well as learning (motor unit recruitment) allows for a wide variety of strengths and endurances of muscles.

The combination of the motor neuron and all the muscle fibers it innervates is called a motor unit. The summation of all the action potentials within the muscle fiber cells of a motor unit is called a motor unit action potential. It is this motor unit action potential (MUAP) that the EMG device picks up (Konrad 2005). Two factors dominantly affect what the MUAP will look like: frequency and amplitude. The frequency of the individual motor unit signals depends on how often the neuron is activated to fire by the central nervous system. Amplitude is determined by the number of muscle fibers within the motor unit (more muscle fibers = more constructive interference = bigger signals) (Miller 2008).

An EMG machine utilizes a differential amplifier to yield a signal. This requires having two primary electrodes that both input a voltage into an op-amp, which then takes the difference and amplifies it. This amplified differential signal is what is then observed on the output device. The op-amp used was from Texas Instruments for a gain of 100. A third electrode is used as a reference ground to eliminate all noise naturally produced by the body. I further connected this reference ground to the cake to ground it to zero. The EMG machine picks up, over time, a reflection of the MUAP. The electrodes report a voltage to the op-amp, but what they really are collecting is the current produced by a difference in voltages between two parts of the muscle fiber (Konrad 2005). This gives an accurate representation of the electrical signals used to yield the work done by the muscles.

Using this, I planned to test which muscles most contributed to the fencing lunge. I would do this by measuring the activity of each muscle during my subject's lunge. This would then be

a taken as a percentage of their max voluntary isometric contraction (MVIC) for that muscle. Using MVIC is the fairest way to compare different muscles, because physiological details such as size, length, and number of motor units can drastically affect the MUAP.

Methods: The earliest attempts were made in the footsteps of the group before me (Estrada 2013). I attempted to use the Iso-180 amplifier, which did not work when prompted. Attempts were done both with the electrodes and function generator, with the output going to an oscilloscope. The function generator had to have an output smaller than 10mV since the smallest gain setting was already 1000 and anything greater than 10V would blow the amplifier. Eventually we got recordings from the function generator to matlab, but it was riddled with noise. This led me to move onto building my own op-amp.

The set up for recordings was such: the three electrodes connected into their respective ports on the circuit. From this op-amp circuit there was a single output, which along with a ground wire, was connected to a National Instruments USB-6211 DAQ data collector. This plugged into the laptop, which used Matlab to record the data. Within Matlab a code named 'data collector' was used, which prompted a single window to record data with. Device three and channel zero were used as the dominant collecting sources. The sampling frequency was always set to 10kHz and the time was usually for 10 seconds. An extra 3.5seconds of recording was added to the end of each trial by the code itself. Two options were given: record and plot. The data was automatically saved—but be wary of forgetting to change the trial name between trials, since it will auto-rewrite the data over. Plot would display the figure but not save it. In the end I always saved my important plots at least as a figure for easy access and editing.

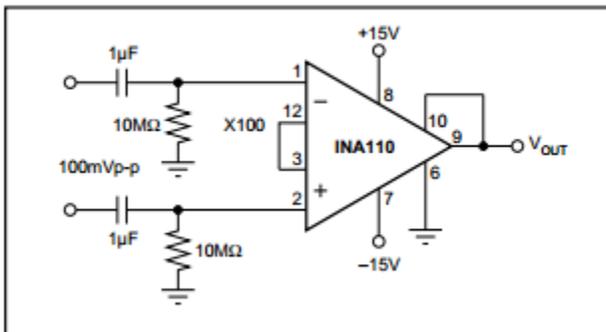
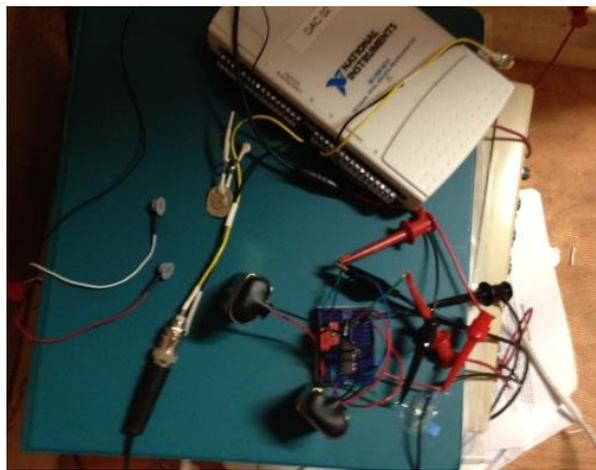


Figure1. Top left: the grounded Faraday cage. Top right: the overall set up. The three electrodes on the far end of the picture connect into the bread board. Two batteries power the op-amp. The output it sent to the National Instruments device and from that to a laptop (not pictured). Bottom left: the diagram of the op-amp used. It has a predicted gain of 100.

Figure 1 displays the experimental setup. The Faraday cage was used to create an isolated environment, since inside was shielded from external signals. The set up for collecting data had the electrode input going into an op-amp and the output was collected ultimately into Matlab. For the above circuit, only minor adjustments were made. Instead of 15V, two 9V batteries were used instead. Also, 2.15 μ F capacitors were used instead of the called for 1 μ F. However this only affects frequency filtering, which we later account for so I do not believe to be any source of error. Using a lesser voltage source might account for a lower gain, but it is still well within the accepted power range of the op-amp. When measuring gain using a function generator, amplification was closer to 40x or 50x than the 100. I have yet to account for this smaller gain, but in my experimentation it was not deemed significant.

Using this set-up, several weeks were spent fine-tuning it in order to get proper and clean measurements. The majority of this time was wasted, since I used the improper approach. To problem solve and find the source of error, always start with what you know actually works. In this case, that would be a function generator and an oscilloscope. This should always be used to test that the circuit is doing what it should be. Once you can confirm it is, you take recordings in matlab using the function generator. If this works then you can proceed to taking measurements with the electrodes in matlab. If at any case it stops working as it should, go back to the function generator and oscilloscope. After that, if things go wrong always check that your circuit is plugged in correctly (remember how the pins are numbered on an op-amp), that your batteries aren't dead, the wires aren't frayed and having normal (very low) resistance, and that no metal is touching or short-circuiting.

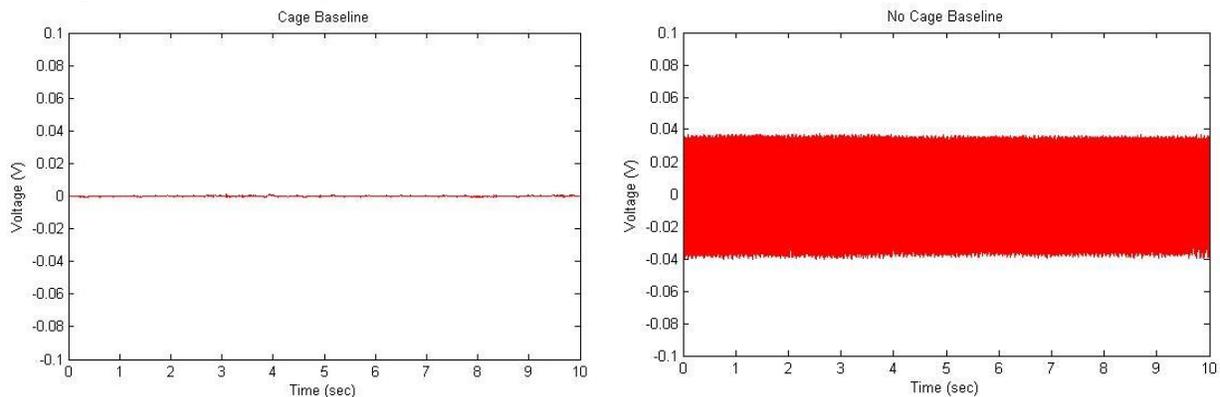


Figure 2. Left: a “nothing” signal taken inside the cage. Right: a “nothing” signal taken outside the cage within the same room. The y-axis of voltage is to the same scale for easy comparison. The contrast between measurements taken is clear: outside of the cage there is a strong signal that would distort or hide most readings from the electrodes. This signal is composed of a 60Hz wave.

In order to get the best possible reading out of the electrodes, several steps were done. The primary factor being the spacing of the electrodes. Kupa, 1995, recommended a 2cm spacing of electrodes to yield the best results. I decided to test this by comparing 2.1, 3.1, 4.0, and 4.9cm spacing using a forearm pulse. From figure 3 below, it can be seen that the 2.1 and 4.9 pulses are the cleanest in terms of baseline noise. Originally I had not filtered the signals (a mistake on my part, since really only the filtered signal is comparable) and the 2.1cm looked much better than the 4.9cm, which is why I chose it (also in agreement with Kupa). In retrospect it was not the only good choice, but I do not think it was a poor one. Regardless, I had chosen to conduct my experiments using the 2.1cm spacing between centers of the electrodes.

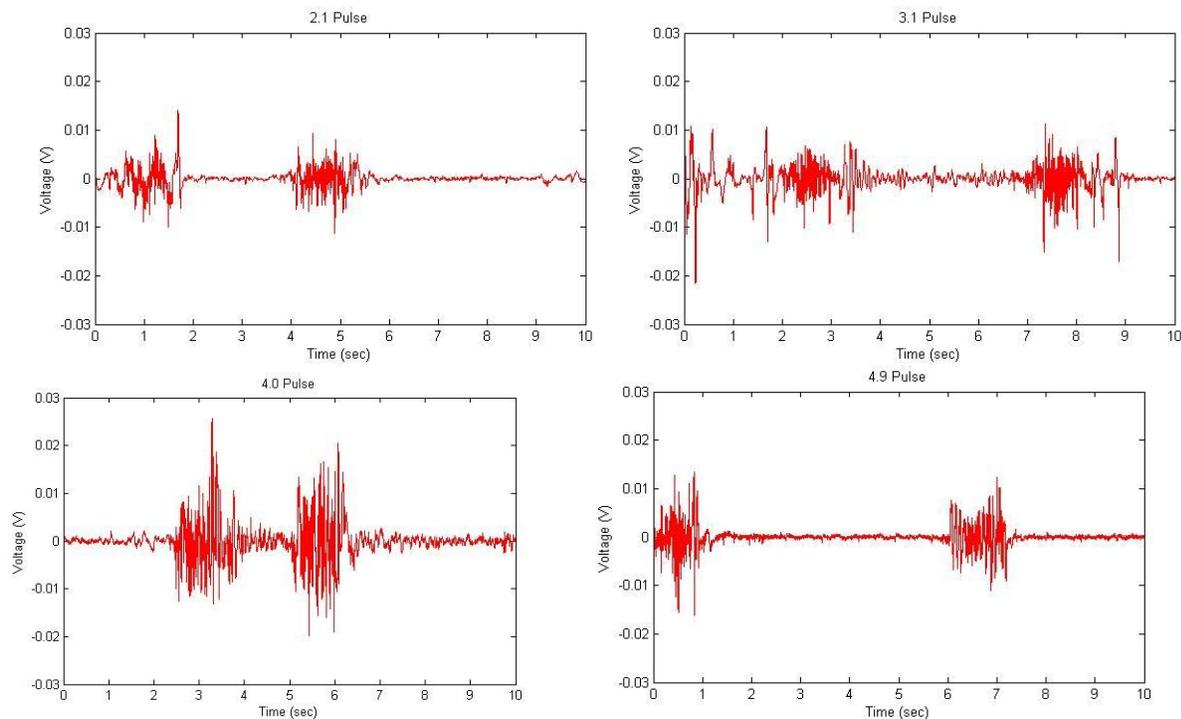


Figure 3. Top left has 2.1cm spacing. Top right has 3.1cm spacing. Bottom left has 4.0cm spacing. Bottom right has 4.9cm spacing. All four were collected by doing two pulses (strong contractions) of the forearm muscle, palm facing up. The electrodes were placed along the median of the forearm in the same position for each recording.

In addition to the spacing of electrodes, additional preparation of the skin could better the signal. Wiping down the areas with alcohol swabs to rid the skin of sweat and dirt helps to ensure a clean working surface. Electrode gel was always used to improve contact between the electrode and skin.

The biggest issue with the recordings was noise. Noise from the outside work (electrical signals) as well as the noise inherent in the setup itself. To reduce much of this noise, I applied a low and high pass filter to the recordings. Only frequencies between 3-200Hz were allowed through, creating a much cleaner signal. This was done using a `filtfilt` function in Matlab (see appendix). The only issue with this is that it could not exclude the 60Hz frequency generated by power cables. Inside the faraday cage this was no problem, but outside the 60Hz dominated or distorted any signals picked up.

Initially I had intended to take measurements at Main Gym on campus because it would provide enough space for my subject to execute a proper lunge (the faraday cage is way too small). In order to do this, my set up had to be completely portable and able to power itself (hence an independent battery-powered op-amp). As such several times I brought the set up outside as to test the viability of measurements outside the Faraday cage, but far enough from machinery. I tested this in the fields between Eury Hall and Main Gym. Successful readings were obtained that lacked any clear or strong 60Hz signal. The baseline noise was thicker, most likely because I could not ground my reference electrode to zero.

Figure 4 shows that the viability of these measurements. Once filtered, the outside signal obtained from regular pulsing of the forearm muscle with reference ground only to the wrist area was good. The thick baseline went away with the low pass filter. The signal itself is was about

as strong as the ones from inside the cage (amplitude of 10mV). Knowing this I was able to hypothesize about other possible experiments with larger movements since my entire set up was mobile and still effective. When I first realized this, it kept the plan of testing the fencing lunge alive, since I had good reason to believe I would be able to take accurate enough measurements at the gym (or really anywhere).

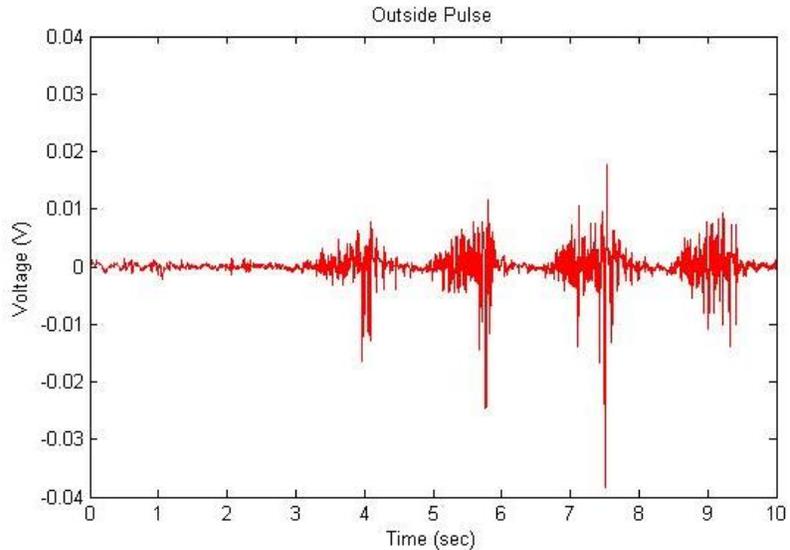


Figure 4. An example of a reading taken outside in the grassy area between Main Gym and Urey Hall. Pulses were done on the forearm with the reference electrode on the wrist. A clean filtered signal was obtained.

The next step was actually testing the set up at Main Gym, where I intended to eventually collect data from my subject. Figure 5 was taken at Main Gym. Despite a heavy raw signal, once filtered provided a signal almost as clean as if it had been taken in the Faraday cage. This was evidence enough that I could get good readings at the Main Gym.

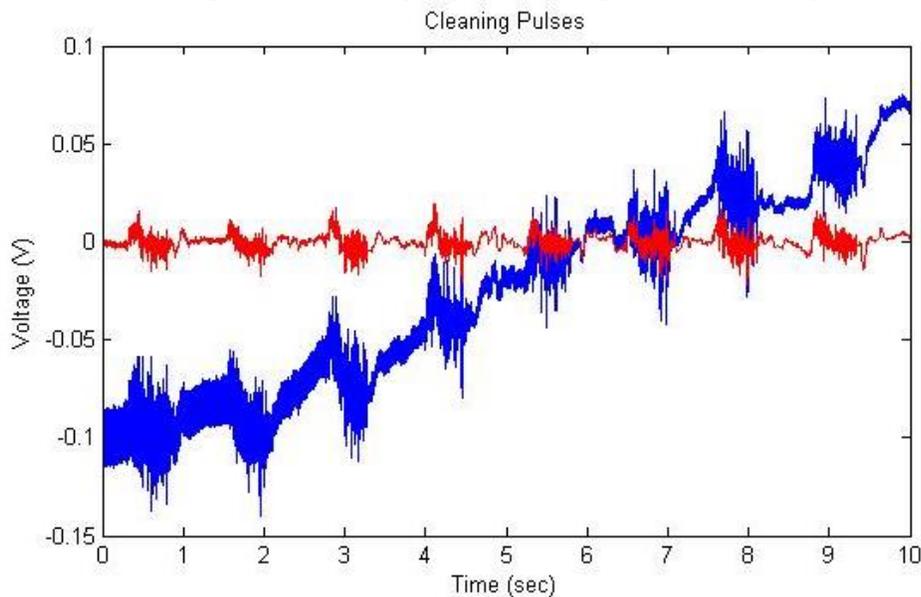


Figure 5. A cleaned signal taken inside Main Gym using forearm pulsing. The blue is the raw signal and the red has been filtered in Matlab.

Along with this was also testing for a timing device to indicate the start of the motion as not to accidentally include artifact noise from motion beforehand. The method for this was to use a battery as a timer signal. The battery was connected to a second channel in the National Instruments data collecting device (channel 1 on the data recorder). When the motion was set to

begin, the battery was plugged into the circuit, inducing a spike (green) as seen below in figure 6. This set up, though developed, ended up not being used. However, doing so also introduced the issue of “cross talk” in which the channels “spoke” to one another when not sufficiently stimulated independently. This would explain why the green signal before the battery is plugged in at 8.5s has some activity when there should have been none (for a battery not attached to the circuit at all).

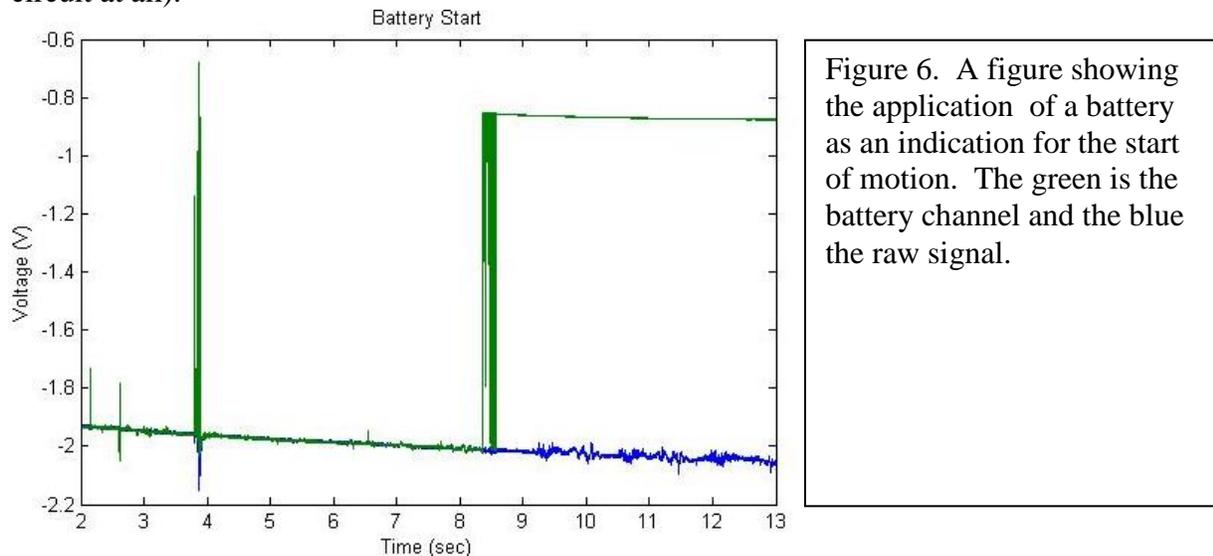


Figure 6. A figure showing the application of a battery as an indication for the start of motion. The green is the battery channel and the blue the raw signal.

Another point that should be noted is that initially when analyzing my data as good or not during the troubleshooting phase, I was always looking at raw signals versus filtered ones. In retrospect I wish I had started filtering sooner, because I often condemned signals as bad which when later filtered were actually quite good. It is difficult to tell with all the background and outside noise, so I prematurely incorrectly judged some data, which attributed to the slow progress I made in making a working EMG collector. Filtering the data would not have been helpful in all cases though. One must also take into consideration that filtering all data before it has been properly recorded can also be misleading.

Ultimately I was unable to test which muscles contributed most to the fencing lunge. Even with my plans to first do the MVIC first then the lunge data collections, it was not meant to be. On the day of data collection my set up fell apart and I could not fully repair it on location. The nature of the wires and that nothing in the circuit as soldered is the reason for this instability. Furthermore, no significant solution had been found for the issue of the long motion of the lunge. The leg components each travel a very large distance and would have yanked out the wires if done with the set-up stationary. Before this issue could be addressed though the circuit fell apart and the experiment was put on hold.

Instead preliminary data was collected on various voluntary contraction types. I had been prompted earlier in the quarter by Jeff about what type of contraction I wanted him to do for a test and I came to realize that there are several types of contractions to be done. I tested three types of contractions over five subjects (TAs) as well as myself. Each type of contraction had two trials, each lasting 10seconds, with three contractions per trial.

A “nothing” trial was done to ensure baseline and that everything was working properly. The subjects sat with their arms at ~90, their elbows resting on their knees. This was the rest position. Then each subject attempted to contract their dominant bicep as hard as possible while lifting a 10lb weight. I prompted each subject with “up” and “down” to attempt to remove

variability from the frequency of motion. Motion was limited to 90-0° approximately, but not strictly enforced. These trials were labeled “MVIC weight”. The next type of contraction performed was the regular weight contraction. The subjects were prompted to lift the weight in the same motion, but this time using only the minimal energy required as they would normally do. These trials were labeled “weight”. Lastly, the subjects were prompted to do this motion without any external weight at all, but attempting to contract their biceps maximally (i.e. flexing). These trials were labeled “MVIC”.

Results and Analysis Due to the large output, my op-amp was saturated by one of the samples and thus their data could not be used, leaving only five sets of data. Very few of the results yielded any conclusions. Too many variables remained uncontrolled during these experiments. Thus the results are not valid and only preliminary hypotheses for further testing will be drawn from the results. All of the below results show red graphs that represent the filtered data. All time trials were done over a period of 10 seconds. The graphs that have a 10^4 along the x-axis are on the 10 μ s scale. They’re just counting the individual points (from the sampling frequency). It is the same scaling as those whose x-axis is just 0-10seconds.

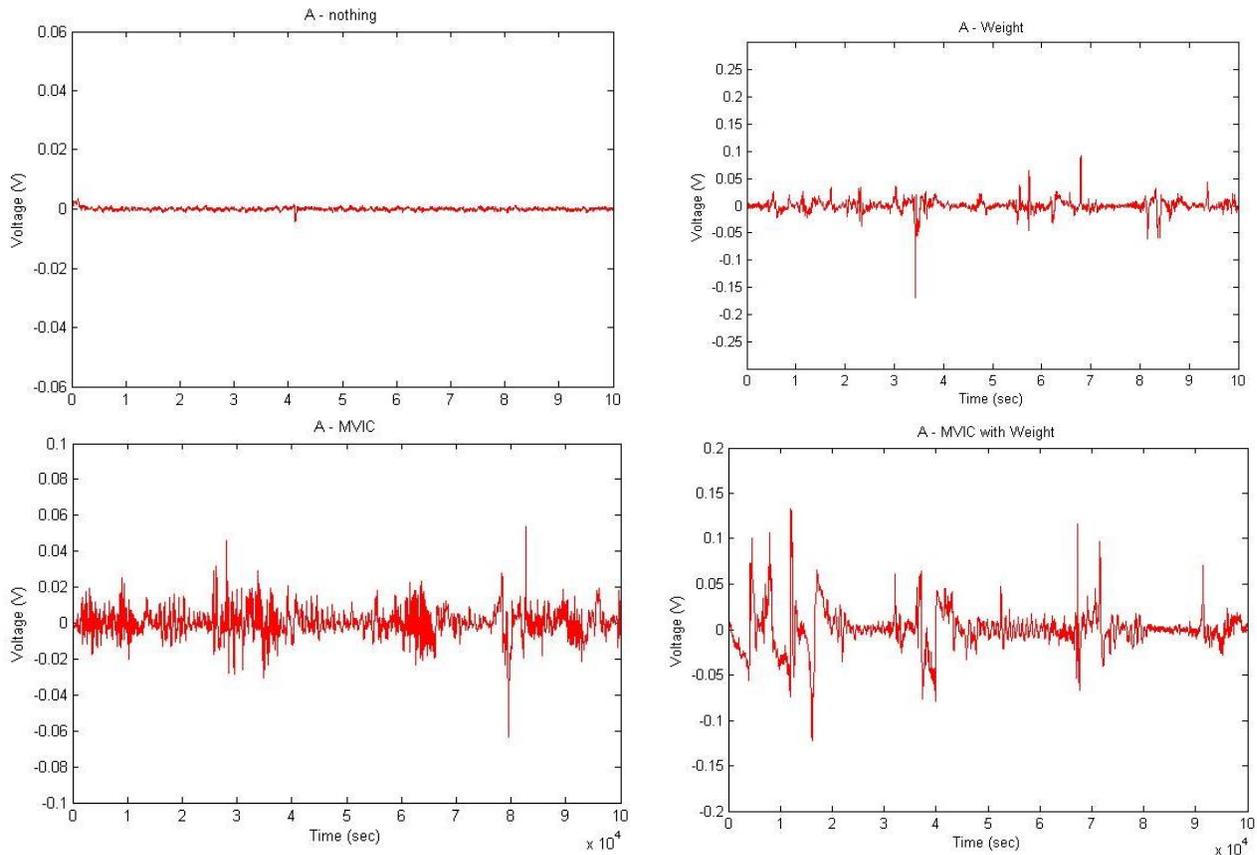


Figure 7. The best four trials performed by subject A. The signals are very noisy and messy and no conclusions were drawn from these results.

For the data in figure 7, no conclusions could be drawn because of the noisiness of the signal. No clear patterns are visible. All trials lasted ten seconds—the $\times 10^4$ comes from

sampling frequency. When the axis shows this, the units were then in $100\mu\text{s}$. This is not significant as it merely scales the whole axis.

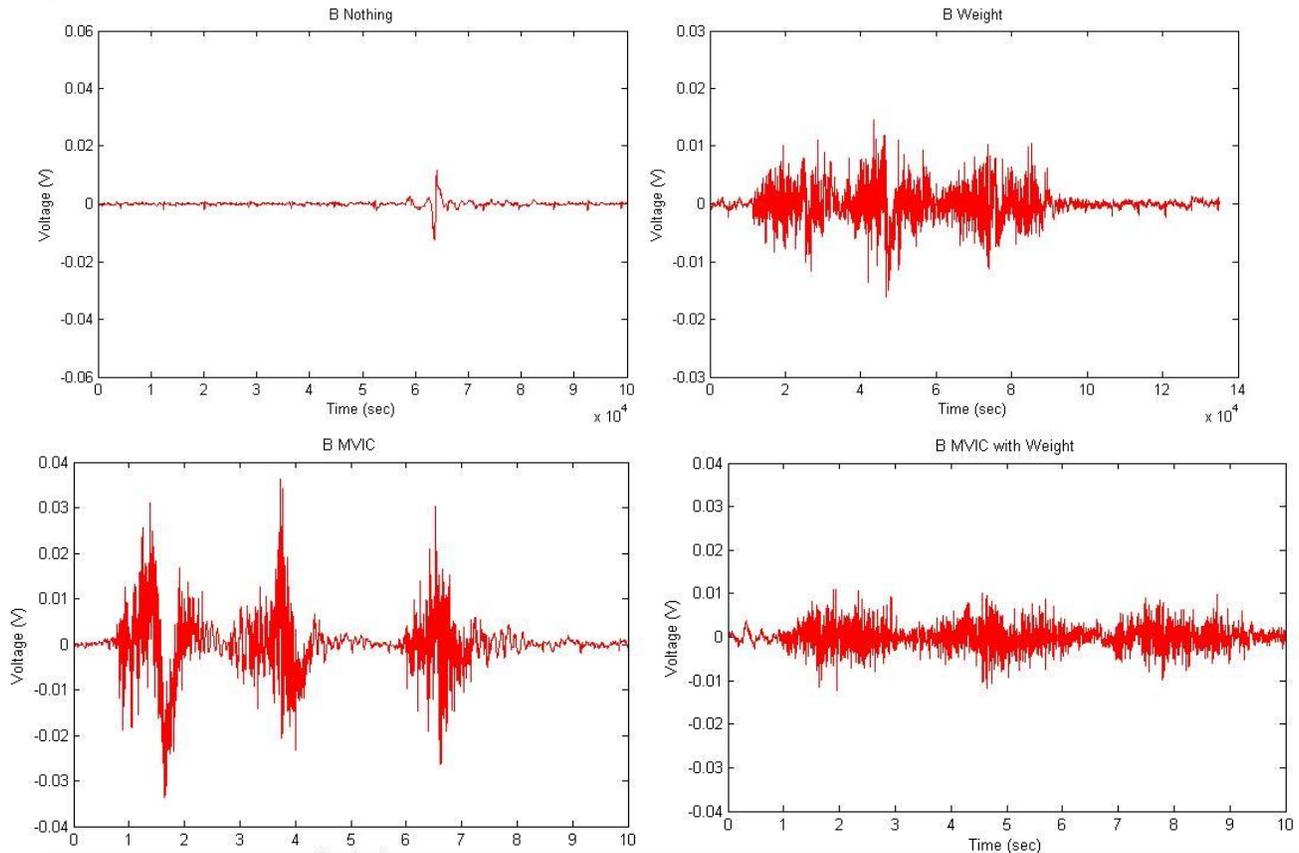


Figure 8: the best four trials performed by subject B. The signals are much cleaner and can be analyzed.

Figure 8 contains data that unlike the other sets can be used for preliminary analysis. It would appear that there is a trend for the MVIC trials to be higher in amplitude and the weight trials to be wider in signal. The MVIC aspect makes sense, since maximum contractions should require more action potentials and thus signals with greater amplitudes. However, the wider (thus prolonged, since the x-axis is time) signals done with weight could perhaps suggest something else about the motor recruitment done.

Figure 9 (next page) shows the data for subject C. The data was not quite good enough for a meaningful analysis. A strange noise artifact was present in the weight measurements—sharp, unnatural peaks. Although the MVIC reading looks very good, the amplitude is much smaller than would be expected compared to the other two contractions.

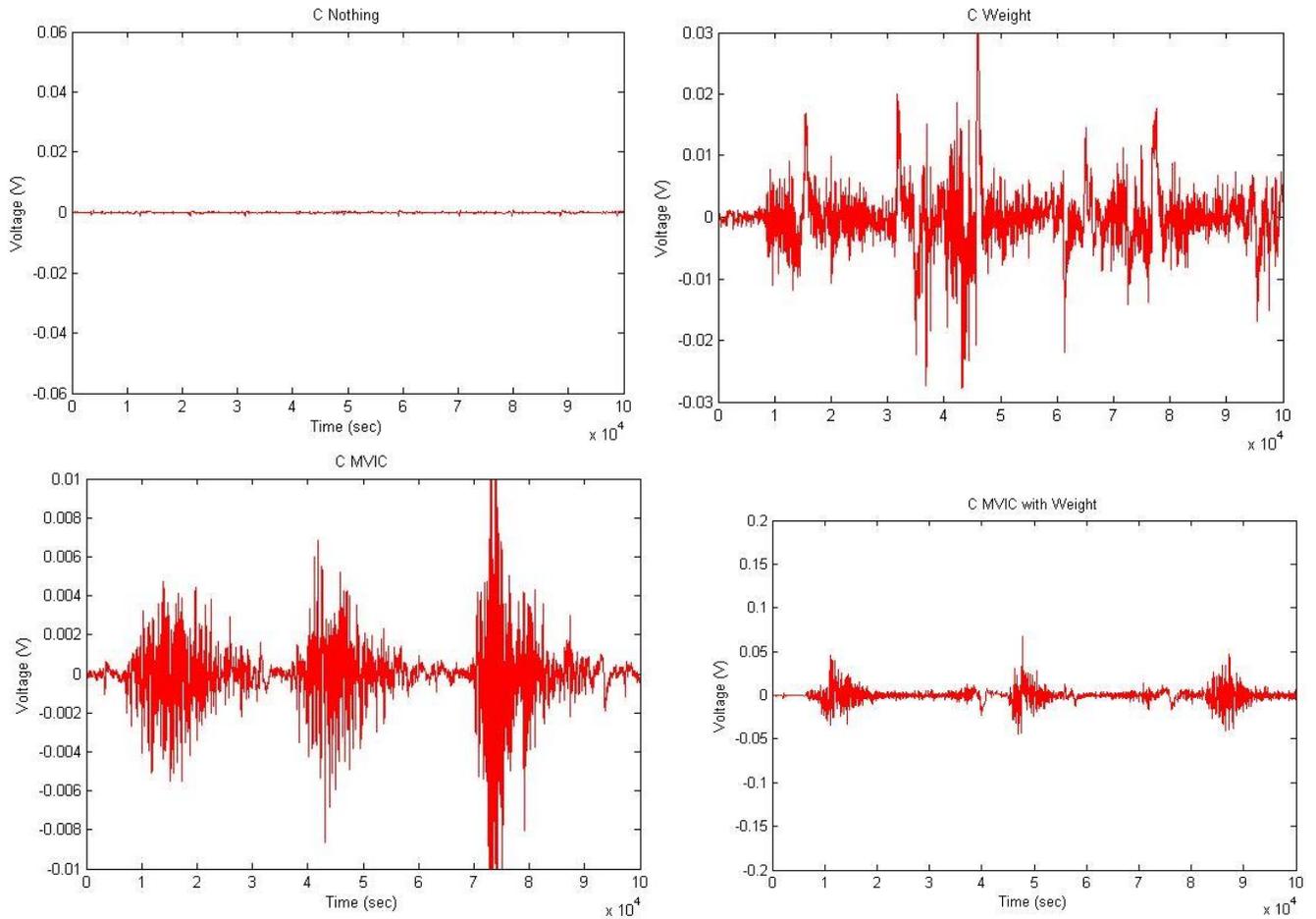


Figure 9. The best four trials performed by subject C. The data of the weight was too noisy for significant analysis. All graphs are on different scales. All were done over a 10 second time period. The cut off peak in MVIC goes to about 0.02.

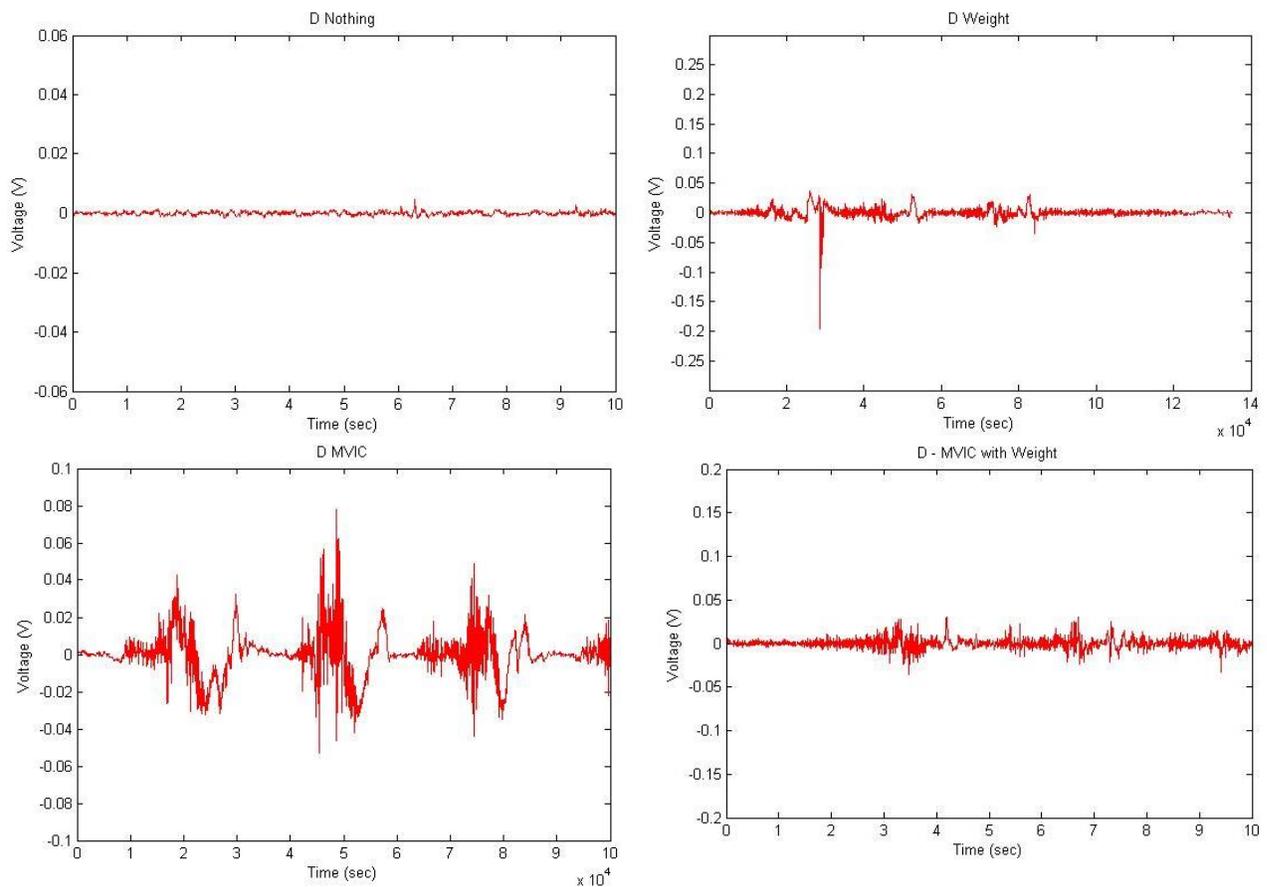
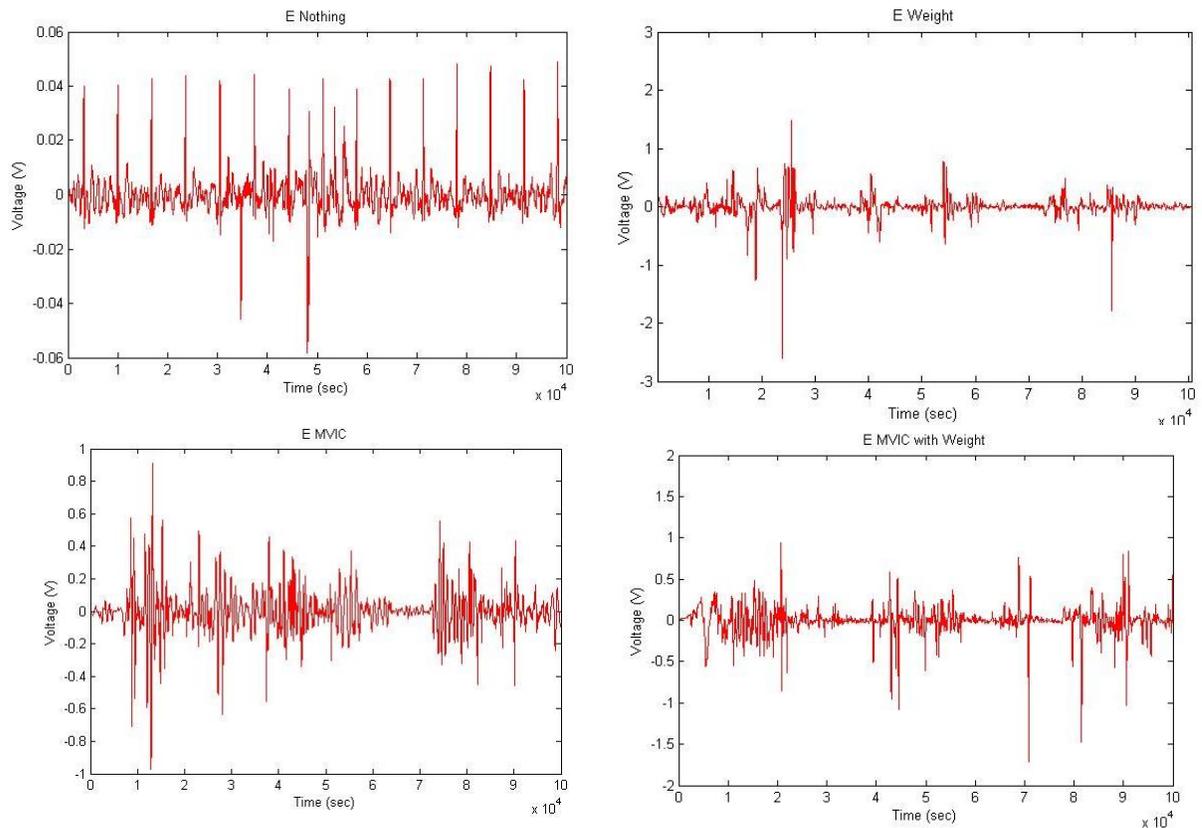


Figure 10 above and figure 11 below. The best four trials performed by subjects D and E respectively. All trials were 10 seconds long. Unknown artifacts (sharp peaks) in measurements make the data not liable for analysis.



Both figures 10 and 11 have artifacts that contaminate the reading. This is so prominent in E that the results are not viable for analysis. This artifact could have come from the wire moving during the motion, or some other signal that somehow originated within the cage between 3-200hZ. In Figure 11, a sharp artifact noise can also be seen in the nothing trial. The reason for this is unknown. It was theorized that this could be the pulse, but even after adjusting the positions of the three electrodes well away from any superficial veins or arteries, the signal persisted. None of this data is valid for analysis. Despite this, this MVIC reading was the highest I had apart from the subject who saturated the op-amp.

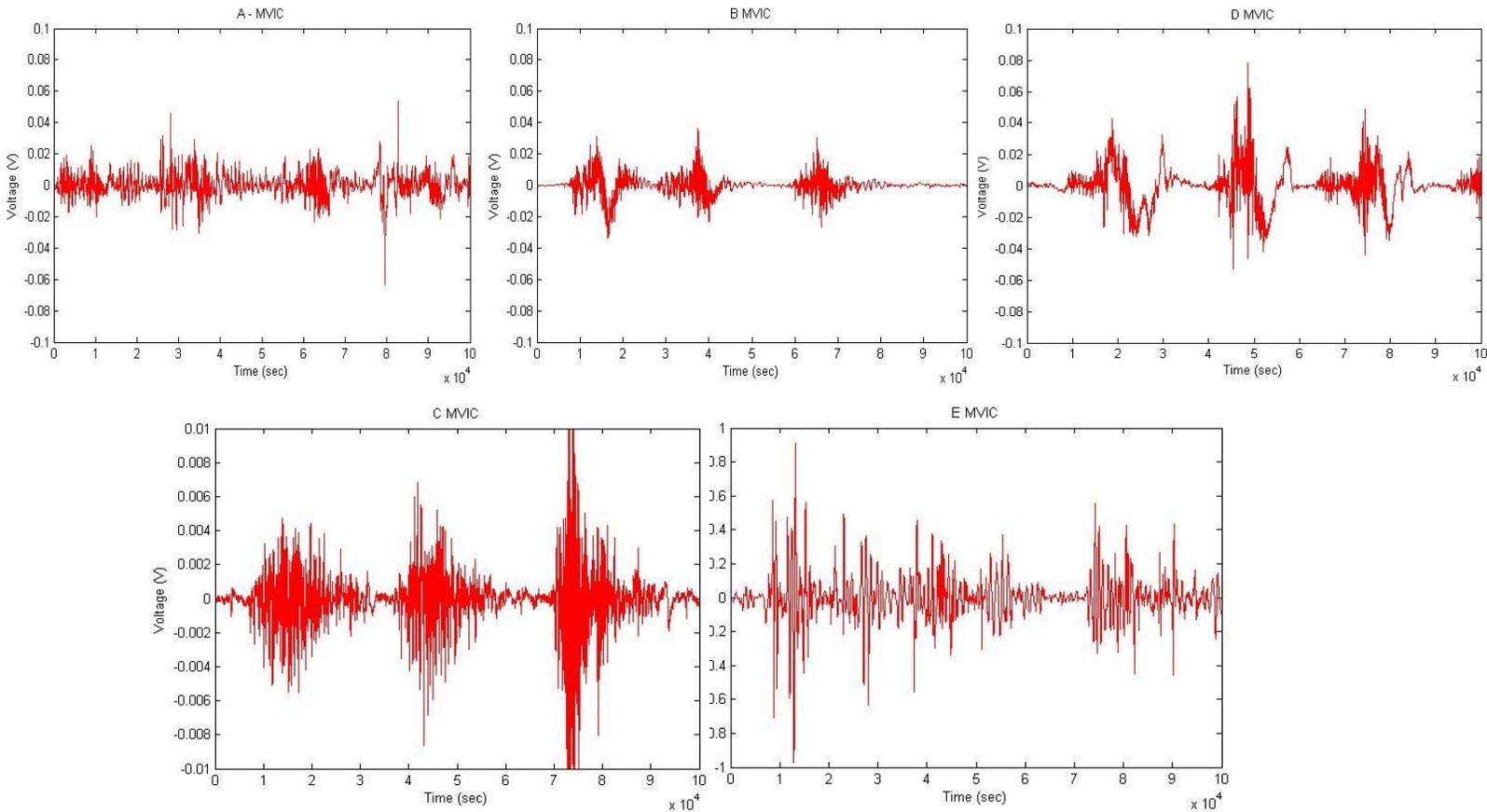


Figure 12 compares the MVIC graphs from all five viable subjects. The top three have the same scaling of 100mV, whereas the bottom left is on 10mV, and the bottom right on 1V. Subject E produced the largest signal in terms of amplitude. Subject C produced the smallest.

Figure 12 shows the comparison of the MVIC results from the five subjects. Only MVIC was compared because it is the standard type of contraction for comparisons. Subject E had a signal that was 100x that of subject C, however I doubt that this subject was actually that much stronger. The data from E is quite noisy, but despite this its surprising amplitude cannot be disregarded. I attempted to attest it to fluke, but several variables could be at play. One of the more reasonable explanations has to do with signal resistance. Since the signal has to travel from the muscle to the skin surface, everything in between provides resistance to the signal. The biggest resistance to this is fat. The more fat one has, the weaker the signal will be. Subject E

was all “skin and bones”, but I am not sure if this was significant enough on its own to account for the difference in strength.

I also took into account the fast fourier transform (FFT) of the plots. This will display the frequency distribution of the signals. This type of data can give insight into the type of motor recruitment done. Again, only preliminary hypotheses could be deduced by comparing the FFTs.

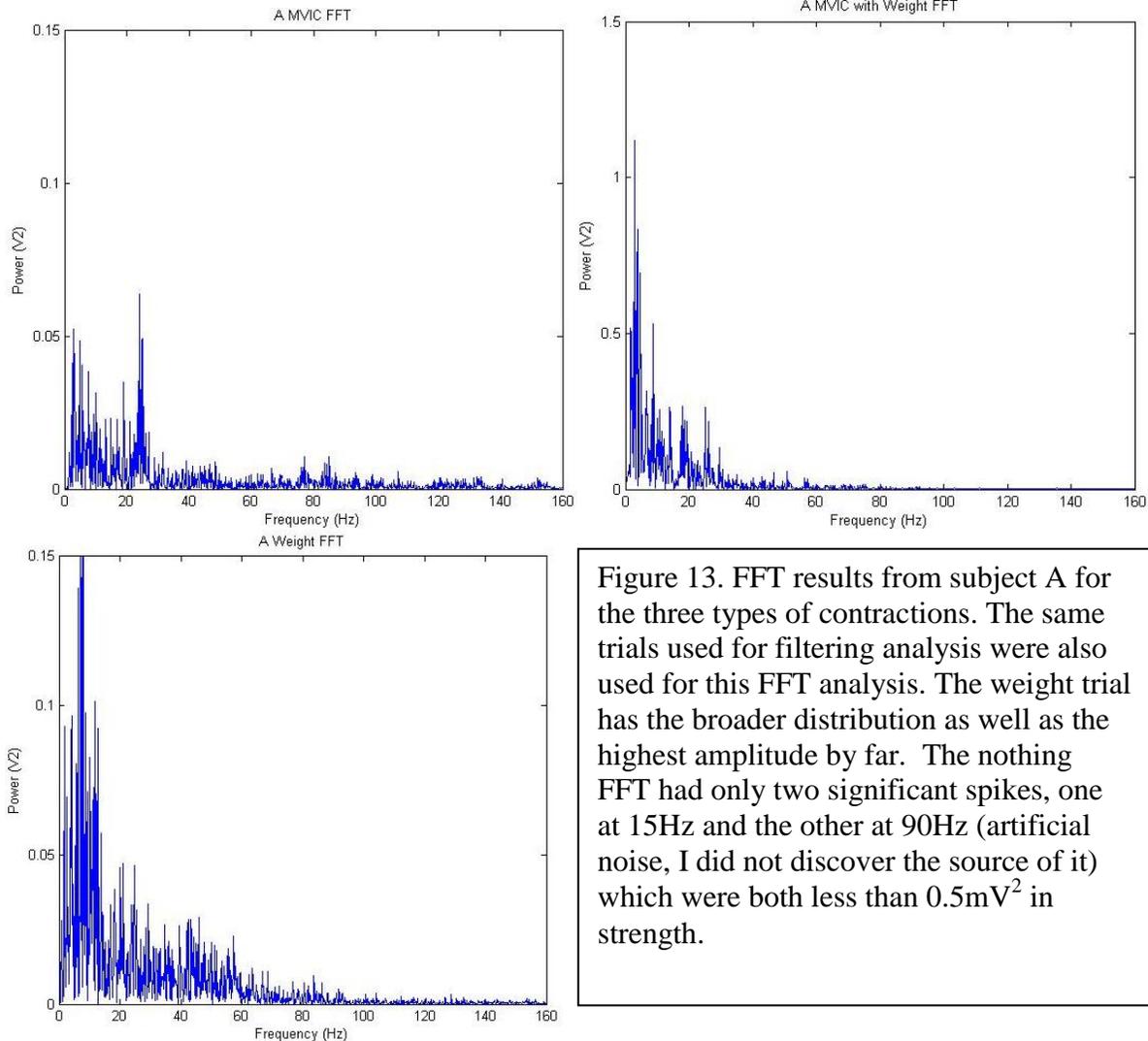


Figure 14 (next page) demonstrates a simple trend I saw amongst one another FFT series. That is, that the FFT of contractions involving weights used more frequencies for muscle fiber contractions than the strictly MVIC one. The solo MVIC FFT also had the greatest power, meaning it was the strongest contraction. This is also logical. Why the MVIC with weight was on the same scale of amplitude as the regular weight I cannot deduce.

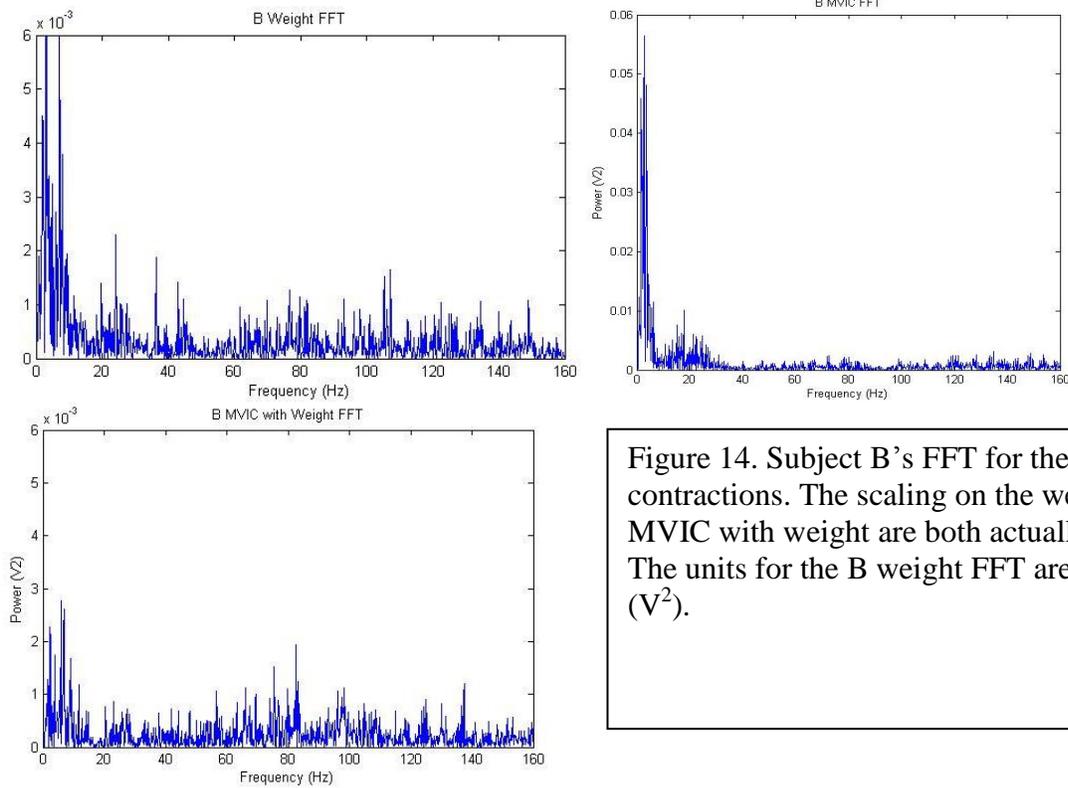


Figure 14. Subject B's FFT for the three contractions. The scaling on the weight and MVIC with weight are both actually in 10^{-3} . The units for the B weight FFT are still Power (V^2).

Figure 15 (next page) also displays the aforementioned pattern with Subject E. The other three subjects were not consistent in only the weight contractions being broadly spread out on the frequency domain AND the MVIC contractions being the strongest. It is cleaner in Figure 15, but getting this result twice at all makes it a more viable hypothesis for further testing. Does having a weight induce the recruitment of more types of motor units at different frequencies because it takes a long time to execute the movement than it would without a weight? It would be an interesting topic to explore further.

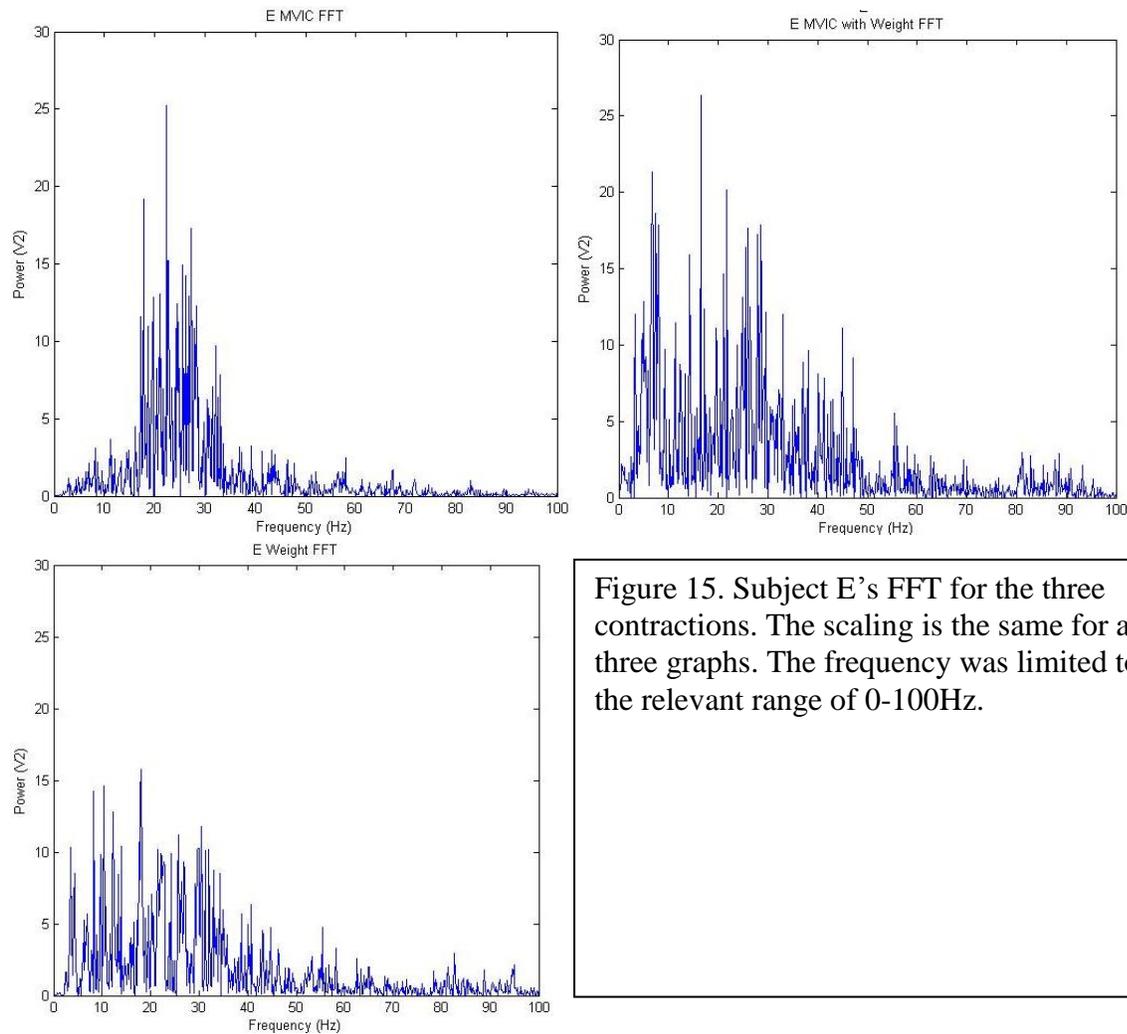


Figure 15. Subject E's FFT for the three contractions. The scaling is the same for all three graphs. The frequency was limited to the relevant range of 0-100Hz.

Conclusion: The bulk of the experiment done in this lab was the building and modification of an EMG device. This device could then measure the motor unit action potentials (MUAP) of various muscles. The initial drive was to use this device to then measure and compare the contributions of various muscles to the fencing lunge. This was to be done by collecting data on the maximum voluntary isometric contraction (MVIC) strength of various muscles and finding the percent of total output each muscle gave during the lunging motion. However, due to technical difficulties when trying to collect data, this aspect was put aside. With very little time left, only a preliminary secondary investigation was able to be carried out. During this, three types of contractions—MVIC, MVIC with a 10lb weight, and just with the weight—were examined to see if there would be differences in the MUAP or FFT distribution and amplitude.

The knowledge to take away from configuring the EMG device would be to always isolate the problem using positive controls before moving onto anything else. A function generator and oscilloscope will go a long way to test various components of a circuit or overall set up. Once you know one element is working the way it should, you can add the next and test that. This is a logical way to pinpoint problems and from there more specific troubleshooting may commence. Also check the circuit for loose, frayed, or short-circuiting wires. Check batteries for floating and running out of energy.

During experimentation there were too many variables to even count and many were not controlled from experiment to experiment. Thus none of the results were reliable, but used as templates for further studies.

From this preliminary data, two conclusions were drawn for further research. One was that weight contractions required a broader spectrum of frequencies, as well as took longer for the muscles to contract. The secondly deduction was that the MVIC tended to have a greater amplitude and power than even the MVIC with weight—so something about the motion of contracting while carrying something is different than that contraction when not carrying something. It might have to do something with motor recruitment training (since it is kind of awkward and one must think about it consciously to really achieve the MVIC measurement with weight). Both of these should be explored further, once the kinks and artifacts have been worked out of the EMG device.

All in all, the experiment gave a successful inside look into the problem solving required to successfully build a circuit, as well as the electric signaling required for muscle contraction. Despite specific hard evidence, it is undeniable that different types of signals can be generated through different motions, with unique frequencies and amplitudes.

Citations

E. J. Kupa, S. H. Roy, S. C. Kandarian, C. J. De Luca. "Effects of muscle fiber type and size on EMG median frequency and conduction velocity." *Journal of Applied Physiology* Jul 1995,79(1)23-32.

Estrada, A., Phung J, "Electromyography" 2013

Konrad P. *The ABC of EMG: a practical introduction to kinesiological electromyography.* Scottsdale, AZ; 2005.

Marnix G.J. Gazendam, At L. Hof, Averaged EMG profiles in jogging and running at different speeds, *Gait & Posture*, Volume 25, Issue 4, April 2007, Pages 604-614, ISSN 0966-6362, <http://dx.doi.org/10.1016/j.gaitpost.2006.06.013>.
(<http://www.sciencedirect.com/science/article/pii/S0966636206001408>)

Miller, Christopher. " Real-Time Feature Extraction and Classification of Prehensile EMG Signals," Department of Computer Science, SDSU, Spring 2008.

Olfat Mohamed, Jacquelin Perry, Helen Hislop, Relationship between wire EMG activity, muscle length, and torque of the hamstrings, *Clinical Biomechanics*, Volume 17, Issue 8, October 2002, Pages 569-579, ISSN 0268-0033, [http://dx.doi.org/10.1016/S0268-0033\(02\)00070-0](http://dx.doi.org/10.1016/S0268-0033(02)00070-0). (<http://www.sciencedirect.com/science/article/pii/S0268003302000700>)

Appendix

I. Data collection code

```
function varargout = data_recorder(varargin)
```

```

% DATA_RECORDER M-file for data_recorder.fig
%   DATA_RECORDER, by itself, creates a new DATA_RECORDER or raises the existing
%   singleton*.
%
%   H = DATA_RECORDER returns the handle to a new DATA_RECORDER or the handle
to
%   the existing singleton*.
%
%   DATA_RECORDER('CALLBACK',hObject,eventData,handles,...) calls the local
%   function named CALLBACK in DATA_RECORDER.M with the given input arguments.
%
%   DATA_RECORDER('Property','Value',...) creates a new DATA_RECORDER or raises the
%   existing singleton*. Starting from the left, property value pairs are
%   applied to the GUI before data_recorder_OpeningFunction gets called. An
%   unrecognized property name or invalid value makes property application
%   stop. All inputs are passed to data_recorder_OpeningFcn via varargin.
%
%   *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only one
%   instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help data_recorder

% Last Modified by GUIDE v2.5 15-Sep-2008 21:31:53

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',    mfilename, ...
                  'gui_Singleton', gui_Singleton, ...
                  'gui_OpeningFcn', @data_recorder_OpeningFcn, ...
                  'gui_OutputFcn', @data_recorder_OutputFcn, ...
                  'gui_LayoutFcn', [] , ...
                  'gui_Callback', []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

```

```

% --- Executes just before data_recorder is made visible.
function data_recorder_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to data_recorder (see VARARGIN)

% Choose default command line output for data_recorder
handles.output = hObject;

% get inputs
handles.ch = [0 0 0 0 0 0 0];
handles.devicenum = 'Dev1';

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes data_recorder wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = data_recorder_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;

% ----- SET UP FILES PANEL -----%
% output directory
function edit1_Callback(hObject, eventdata, handles)
if isfield(handles,'outputdir')
    set(hObject,'String',handles.outputdir);
else
    set(hObject,'String',pwd);
end
function edit1_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

% filename
function edit2_Callback(hObject, eventdata, handles)
handles.filename = get(hObject,'String');
guidata(hObject,handles);
function edit2_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

% browse output directory
function pushbutton1_Callback(hObject, eventdata, handles)
handles.outputdir = uigetdir;
guidata(hObject,handles);
edit1_Callback(handles.edit1, eventdata, handles)

```

```

%-----SELECT CHANNELS-----%

```

```

function radiobutton1_Callback(hObject, eventdata, handles)
handles.ch(1) = get(hObject,'Value');
guidata(hObject,handles);
function radiobutton2_Callback(hObject, eventdata, handles)
handles.ch(2) = get(hObject,'Value');
guidata(hObject,handles);
function radiobutton3_Callback(hObject, eventdata, handles)
handles.ch(3) = get(hObject,'Value');
guidata(hObject,handles);
function radiobutton4_Callback(hObject, eventdata, handles)
handles.ch(4) = get(hObject,'Value');
guidata(hObject,handles);
function radiobutton5_Callback(hObject, eventdata, handles)
handles.ch(5) = get(hObject,'Value');
guidata(hObject,handles);
function radiobutton6_Callback(hObject, eventdata, handles)
handles.ch(6) = get(hObject,'Value');
guidata(hObject,handles);
function radiobutton7_Callback(hObject, eventdata, handles)
handles.ch(7) = get(hObject,'Value');
guidata(hObject,handles);
function radiobutton8_Callback(hObject, eventdata, handles)
handles.ch(8) = get(hObject,'Value');
guidata(hObject,handles);
%-----%

```

```

%----- GET RECORDING PARAMETERS -----%

```

```

% get frequency

```

```

function edit3_Callback(hObject, eventdata, handles)
handles.Fs = str2double(get(hObject,'String'));
guidata(hObject,handles);
function edit3_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit4_Callback(hObject, eventdata, handles)
handles.T = str2double(get(hObject,'String'));
guidata(hObject,handles);
function edit4_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

%-----%

```

```

%-----RECORD-----%

```

```

function pushbutton2_Callback(hObject, eventdata, handles)
% set device number
edit5_Callback(handles.edit5, eventdata, handles);
devicenum = handles.devicenum;
% set channels
channels = [];
for ichan = 1:8
    if handles.ch(ichan)~=0
        channels = [channels ichan-1];
    end
end
Fs = handles.Fs;
dr_record_analog_only(handles.outputdir,handles.filename,channels,handles.Fs,handles.T,device
num);
%-----%

```

```

function pushbutton3_Callback(hObject, eventdata, handles)
curdir = pwd;
cd(handles.outputdir);
load([handles.filename, '.mat']);
cd(curdir);
time = [0:size(data,1)-1]/handles.Fs;
figure(1);
plot(time,data);

```

```

function edit5_Callback(hObject, eventdata, handles)
handles.devicenum = get(hObject,'String');
guidata(hObject,handles);

```

```
function edit5_CreateFcn(hObject, eventdata, handles)
handles.devicenum = get(hObject,'String');
guidata(hObject,handles);
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

II. Filtering code

```
m=mean(data)
mdata=data-m;
[B,A] = butter(1,[3/1e4 200/1e4]);
mdata_filt = filtfilt(B, A, mdata);
plot(mdata,'b'); hold on; plot(mdata_filt,'r')
```

III. FFT code

```
m=mean(data);
mdata=data-m;
[B,A] = butter(1,[3/1e4 200/1e4]);
mdata_filt = filtfilt(B, A, mdata);
X=tdata;
Y=fft(mdata_filt,135000);
Pyy=Y.*conj(Y)/135001;
f=10000/62501*(0:62502);
plot(f(1:1000),Pyy(1:1000))
```