# Electromyography

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Modern Physics Laboratory: Biological and Quantum Physics, 2013

**Abstract**

This project entails taking electromyography readings from the biceps and triceps of multiple subjects. Our goal, through a series of experiments, focused on finding correlations of the skeletal muscle(s) being tested. Further analysis of the EMG signals collected via electrodes display results of motor unit firing frequencies and voltages in relation to force.

# I. Introduction & Background

Muscle cells, like other excitable cells, rely on action potentials to function and contract. When a motor neuron synapses, onto a muscle fiber, an action potential is propagated along the plasma membrane and down T tubules. Once the action potential reaches the Sarcoplasmic reticulum, $Ca^{2+}$ ions are released into the cytosol and bind to the troponin. The tropomyosin that is normally blocking the myosin binding sites of the actin filament is then shifted, exposing the sites. This allows the myosin head to form a cross bridge and pulls the actin filament towards the center of the sarcomere to cause muscle contraction. $Ca^{2+}$ is returned to the SR by active transport. Throughout this process, there are changes to the membrane potential due to: action potentials and $Ca^{2+}$ being released and returned to the SR, and the equipment being used for the electromyography readings detect and report this.

Motor neurons transmit electrical signals that cause muscle fibers to contract simultaneously. A motor unit contains one motor neuron that innervates several muscle fibers in the same manner as described above, and these motor units fire at various frequencies. The motor axons synapse on fibers distributed within the muscle so that the contractile force is evenly spread. Muscles work in antagonistic pairs so that when one contracts, the other relaxes. The biceps and triceps are a prime example of this, and the experiments conducted show a variety of results.

# II. Methods & Materials

*Equipment*

The equipment used to perform the experiments include a Faraday cage, Silver/Silver Chloride electrode pairs, electrolytic gel, adhesive electrode washers, preamplifiers, a DAM 80 Differential amplifier, an ISO Isolated Bio-amplifier, a National Instruments USB-6211 data acquisition box. For specified tasks, varied weights (5, 10, 15, 20 lbs) and a gyroscope that attaches to a hand was used to measure the speed during a period of time (Figure 1).

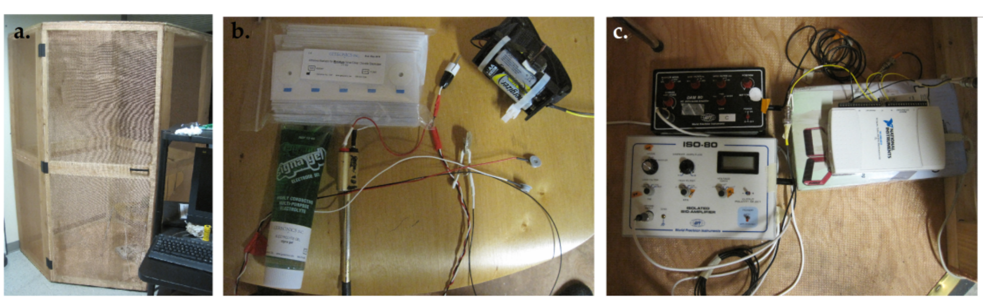


**Figure 1: a)** Faraday cage **b)** Adhesive washers, gyroscope, electrolytic gel, preamp, Silver/Slver Chloride electrode pair **c)** DAM 80 Differential amplifier, ISO Isolated Bio-amplifier, National Instruments USB-6211 DAQ

The Faraday cage is made of wood and copper mesh as to block external electric fields that may affect signal recordings. It reduces the noise caused by the 60 Hz frequency from the power line that is present in the building when readings are taken outside the cage (Figure 2).

The electrodes are used to measure the electrical activity of the skeletal muscles, and because these signals are small – on the order of mV – they are amplified so the DAQ box can transmit these signals to the laptop and such recordings can be made. The electrolytic gel enhances the electrodes' measuring ability.

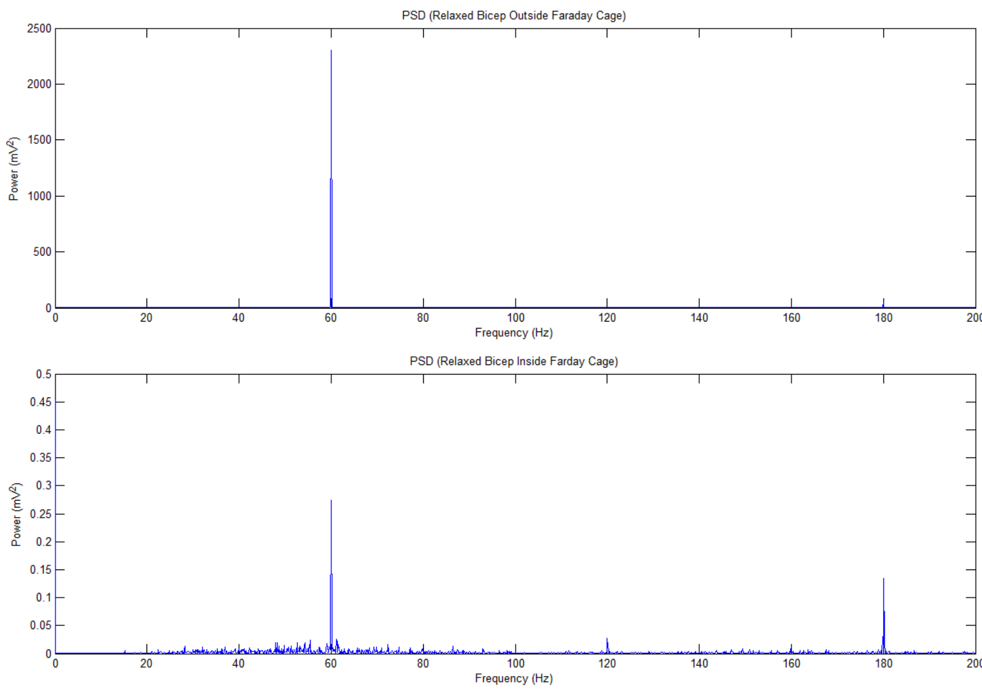


**Figure 2:** The 60 Hz signal from the power line is evident after the power spectral density (Appendix.1 )is taken for signals inside and outside the cage. When comparing the two plots, he magnitude is much more significant outside the cage and minimized inside to a point of non-interference with the EMG signals as compared to the plots to be shown.

*Set-up Procedure*

An electrode washer is stuck on to each electrode, and the electrolytic gel is applied onto the center of the electrode. The surface of the sticker is removed and adheres the electrode onto the participant's skin on the muscle of interest. These electrodes are connected to the amplifying device which outputs to the DAQ box connected to the laptop, which is taking readings in MATLAB. The laptop remained outside of the Faraday cage, whereas all other equipment including the subject were inside. Depending on the task, only one set of electrodes were used to measure the biceps, or 2 sets were used simultaneously with the gyroscope to measure the biceps, triceps, and speed. This equates to selecting one, two or three channels to record from in the MATLAB GUI (Figure 3).

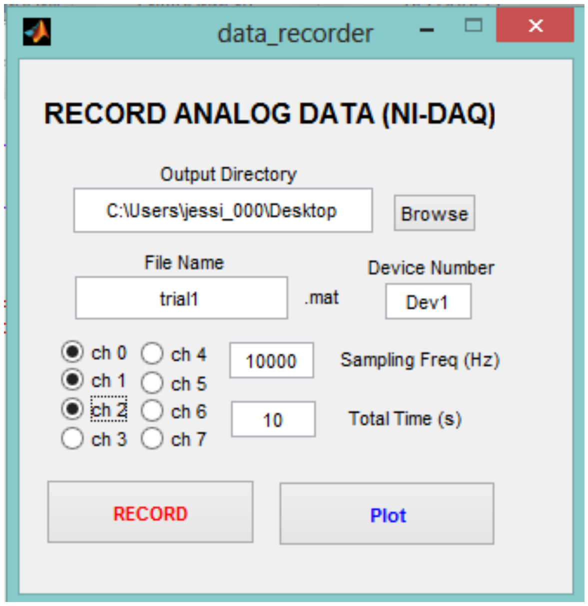


**Figure 3:** MATLAB data recorder GUI. The directory chosen to where .mat files should be saved. Channels are selected based on how many signal recordings are needed for a specific experiment. Each trial must be renamed to avoid overwriting, the sampling frequency is set to 10000 Hz, and time to record data may be varied though the data recorder is default to set to record an addition 3.5 seconds to avoid short misrecordings (A.2)

*Experiments & Tasks*

Four experiments were performed and each demonstrated the behavior of the muscle influenced by various variables. These include taking measurements to view the results for torque versus $V_{RMS}$, gyroscope and biceps and triceps correlation, and muscle fatigue.

1. **Force vs. $V_{RMS}$**

The first experiment was based on finding the relationship between the $V_{RMS}$ and the torque. Initially, it was predicted that the relationship would be directly proportional but how the relationship behaved was unknown. It was undetermined whether it would have been a linear, exponential, or polynomial (etc.) progression throughout time. In order to determine the type of relationship, various weights were used to influence changes in Torque, and readings were taken from the biceps. Torque was set as the independent variable and Vrms as the dependent variable.

This experiment is done two times. The first session served to determine where the electrodes should be placed on the arm to obtain the most sufficient readings. The experiment is then repeated with some adjustments to get better recordings. Both sessions only required the basic experimental set up. Prior to connecting the subject to the equipment, the tip of right hand is measured to the elbow to obtain length r. Its significance shows as follows:

Recall ,

$$\tau = \mathbf{F} \ \mathbf{x} \ \mathbf{r} \tag{1}$$

$$= Frsin\theta \tag{2}$$

Where **F =** force (N) , r = length of rotating arm (m), θ = angle between **F** and rotating arm (°)

$$\mathbf{F} = m\mathbf{a} \tag{3}$$

$$\mathbf{W} = m\mathbf{g} \tag{4}$$

Where m = mass (lb. converted to kg) , **a** = acceleration, **W** = weight (N), **g** = gravity (9.8 m/s$^2$).

The subject is holding the weight with their forearm parallel to the ground, and bent at $\theta = 90°$

$$sin\ \theta = 1 \tag{5}$$

$$\tau = Fr \tag{6}$$

Equations 4 and 6 are used to find torque in this experiment.

*First Session*

One task with three 7-second trials is performed only using one subject. Each trial is a four-part sequence due to the four weights used. During the first trial of the first task, the electrodes are placed 2cm apart on the subject's right arm. The subject is then asked to remain relaxed so a relaxed recording can be taken to analyze noise. The subject prepares to pass the 5 lb. weight to their right hand and hold it with their right arm at 90°. The reader starts to record and immediately tells the subject to pass and hold the weight for 7 seconds. This is repeated for the 10, 15, and 20 lbs. weights (in consecutive order) to serve as one trial. This trial is repeated two more times without any significant rest time for the subject.

This task is repeated with the same procedure two more times with the electrodes placed 4 cm then 6 cm apart.

*Second Session*

The same procedure is done on two subjects but only recorded with the electrodes 4 cm and 6 cm apart to get more accurate results. There was also no passing; subjects were already holding the weight before the recording started to ensure that the weight is being held the entire time. Subjects were allotted rest time after holding any weight. After the 5 lbs., subject rested for 2 minutes; after 10 lbs., rest time was 3 minutes; and a 5-minute rest time following the 15 lbs., then 20lbs. After the 4 cm recording, the subject rested for 10 - 15 minutes before beginning the 6 cm run.

## 2. Gyroscope

After recordings signals from just the biceps, a gyroscope was introduced to measure speed along a single axis. The speed is recorded as a voltage between 0-3 V, and the angular velocity can be obtained by subtracting the baseline voltage (of a relaxed muscle) from the gyroscope voltage then dividing that by 0.003 V/(°/s). From here, correlation of the muscle activity to the arm speed can be analyzed.

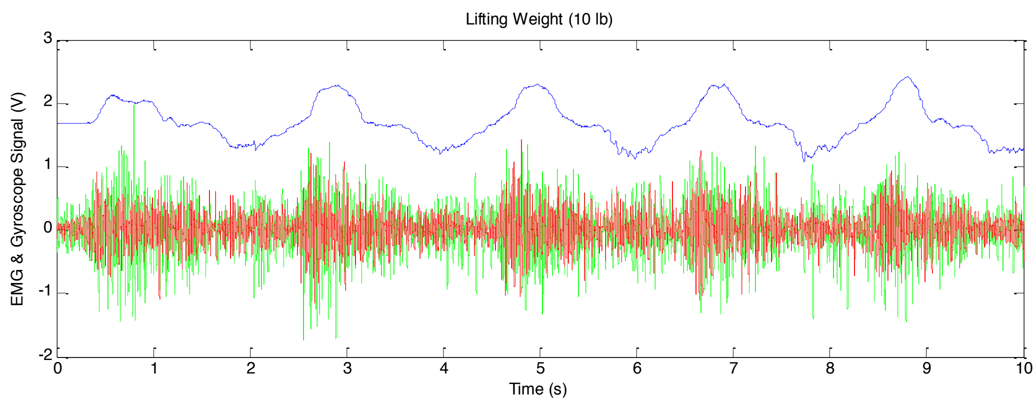


**Figure 4:** Plot of gyroscope and EMG (biceps and triceps) data acquired in a trial where subject lifted 10 lbs repetitively. The larger muscle activity correlates to the highest speeds, but further analysis can be done on these raw signals.

## 3. Biceps and Triceps

For further analysis with the gyroscope, different experiments were done to show how antagonistic pairs work together. By noting the cycles of movement and speed from the gyroscope, it is possible to see certain patterns present between the biceps and the triceps in different exercises.

The experimental set-up was the same with the addition of another set of electrodes (placed about 3- 4 cm apart) and amplifier measuring the triceps, and the use of the gyroscope. Two tasks each with three 10-second trials are performed in a randomized order using three subjects. Each trial consists of a three-part sequence. Only the 10 lb. weight is used, and one baseline recording is taken.

*First Task (Lift)*

For the first part of sequence, the subject had to raise their arm up and point to a target (a piece of tape) that was placed in front of them so their arm is lifted 90degrees. The subject has to do this as fast and as many times that they can within 10 seconds. The second part of the sequence required the subject to repeat the same procedure with a 10 lb. weight. Immediately after completion, the third part of the sequence starts by repeating the first part to determine whether the subject overshoots (doing faster lifts hence increasing the number of lifts).

*Second Task (Lower)*

The procedure is the same as the lift task except the subject is asked to initially have the arm up (forearm next to bicep and then lower the arm down 90° to the target) with their elbow by their side. The lift and lower tasks were done in random order for each subject; for example: lift, lift, lower, lift, lower, lower.

One subject was also asked to perform the task with their arm lifted at 90° to begin with (elbow to shoulder path parallel to the ground). The subject then lowers their arm until it is fully extended, then retracts it back to 90° and does this several times.

### 4. Muscle Fatigue

This experiment was performed to show how the electrical activity of the muscle evolves as the muscle fatigues. The experimental set – up is basic, in addition to another set of electrodes to measure the triceps. The subject held a 10lbs weight for 70 seconds but only three 10sec recordings were taken 20 seconds apart (i.e. at 0-10 seconds, 30-40 seconds, and 60-70 seconds).

## III. Results & Analysis

### 1. Force versus $V_{RMS}$

The goal of this experiment was to determine the type of relationship between the $V_{RMS}$ and the torque. However, because the first session was performed solely to determine how far apart the electrodes should be placed, thorough analysis will be made for the second session. The first session only confirmed our prediction of the relationship being directly proportional, and that the electrodes obtained the best readings when the electrodes are 4 cm or 6 cm apart.

Because there were only two subjects, the data was compared amongst these individuals to determine whether there is a particular behavior that characterizes the $V_{RMS}$ -Torque relationship.

*SUBJECT #1 Data Analysis*

4 cm Task:

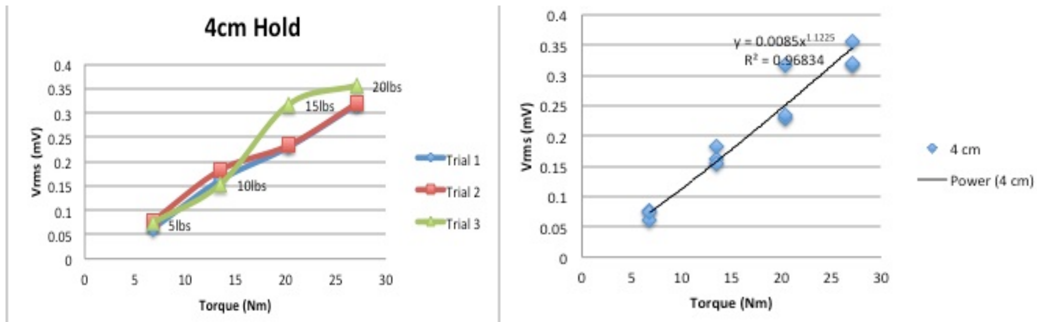


**Figure 5:** The plot on the left depicts the consistency amongst all three trials, and the figure on the left reveals the kind of relationship $V_{RMS}$ shares with Torque. Trials 1 and 2 show consistency, whereas trial 3 tapers off, there being a significant increase of the upward slope when torque is between 15Nm – 20Nm. This is possibly due to the subject's muscle fatigue that developed throughout the experiment since it lasted for about three hours. According to the figure on the right, it appears that the behavior takes on the form of a power equation, $ax^b$, more specifically $V_{RMS} = 0.0085T^{1.1225}$. This relationship is confirmed by the correlation coefficient, $R^2 = 0.96834$, that has a value closest to 1 ($R^2$ shows how close the data points match the specified trend line with 1 or -1 being a match, and 0 being far from a match).

6 cm Task:

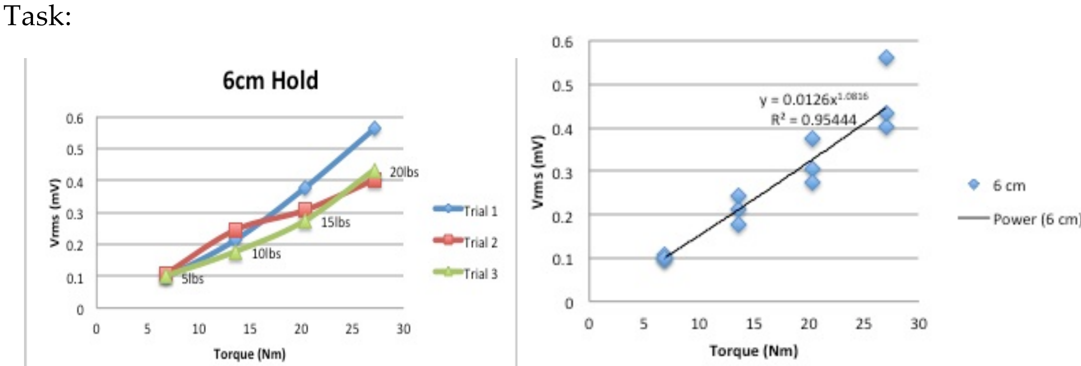


**Figure 6:** Compared to the 4cm task, the trials in the 6cm do not appear as consistent in the figure on the left. This is most likely due to muscle fatigue that has developed tremendously after the 4cm task. Similar to the 4cm task, the figure on the right shows that the $V_{RMS}$ – Torque relationship is described by the power equation, $V_{RMS} = 0.0126T^{1.0816}$ with an $R^2$ value of 0.95444.

It can be inferred that based on the data from Subject #1, the relationship between $V_{RMS}$ and Torque seems to follow the power equation of the form $V_{RMS} = aT^b$.

*SUBJECT #2 Data Analysis*

4 cm Task:

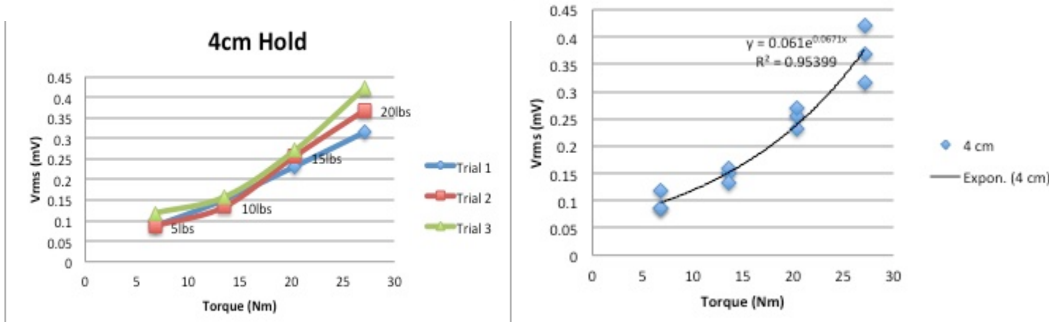


**Figure 7:** The plot on the left shows more consistency amongst the trials compared to Subject #1 data. However, according to the plot on the right, the relationship between the $V_{RMS}$ and Torque behaves as an exponential in the form of $ae^{bT}$ or more specifically, $V_{RMS} = 0.061e^{0.061T}$ . The $R^2 = 0.95399$ value being the closest to 1 confirms this.

6 cm Task:

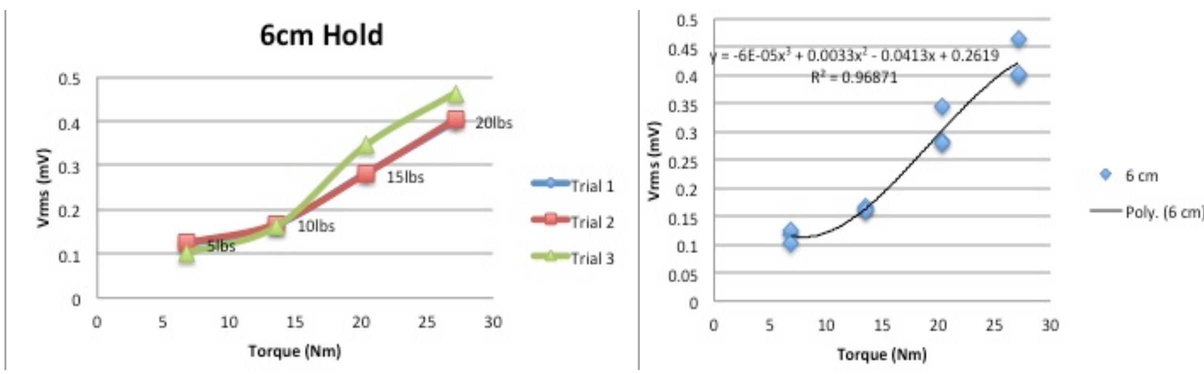


**Figure 8:** Trials 1 and 2 are much correlated as seen by the figure on the left, but the third trial isn't as consistent possibly due to muscle fatigue development. Like that of Subject #1, Subject #2 may have been tired during the final part of this long experiment. There is a steep, positive slope when the Torque is between 15Nm – 20Nm which is somewhat similar to Subject #1's data from the 4cm task. Also, unlike the previous task, the relationship between $V_{RMS}$ and Torque is different. The figure on the right depicts a polynomial behavior at least to the order of 3, in the form of: $V_{RMS} = -6E\text{-}05T^3 + 0.0033T^2 - 0.0413T + 0.2619$ .

Unlike Subject #1, Subject #2 has a different behavior for each task.

## 2. Gyroscope

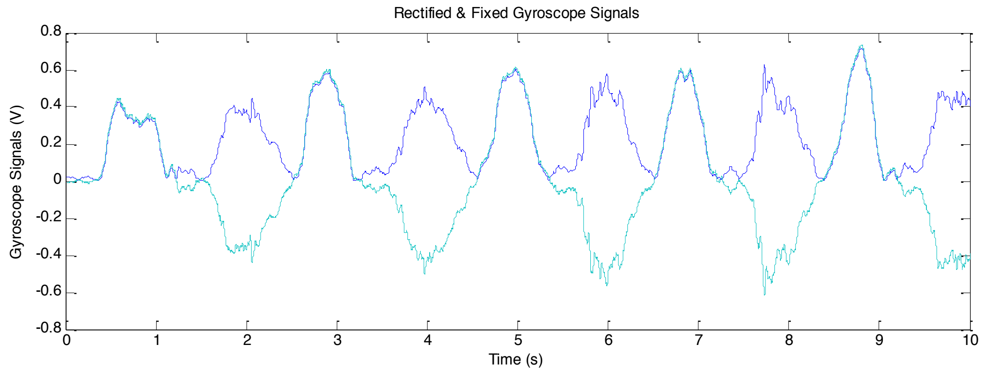


**Figure 9:** The plot shows the raw gyroscope signal with the subtracted baseline and the rectified gyroscope signal. In this trial, the subject lifted a 10 lb. weight multiple times to a target in the same manner as described previously.

By looking at Figure 9, we can estimate the time periods where the gyroscope is at a high speed by looking at the signal. The gyroscope reports a voltage between 0-3 V correlating to the movement it experiences. After subtracting the baseline from the gyroscope signal, we can divide that voltage by 0.003 V/(°/s). Angular velocity can be found by the following calculation:

$$\omega = \frac{V_{gyroscope} - V_{baseline}}{0.003} \tag{7}$$

The average speed (°/s) for a certain time period can be calculated by taking the mean of the angular velocity (found with eqn. 7) over the times selected.

| Time (s) | Bicep $V_{RMS}$ (V) | Tricep $V_{RMS}$ (V) | Average Speed (°/s) | movement |
|---|---|---|---|---|
| 0.50-1.00 | 0.2393 | 0.4518 | 51.3310 | up |
| 1.75-2.25 | 0.1600 | 0.2627 | 76.5448 | down |
| 2.75-3.10 | 0.2560 | 0.4194 | 134.7209 | up |
| 3.75-4.25 | 0.1277 | 0.2219 | 97.7975 | down |
| 4.75-5.10 | 0.3046 | 0.4370 | 119.2515 | up |
| 5.75-6.25 | 0.2032 | 0.2843 | 87.6786 | down |
| 6.70-7.00 | 0.2548 | 0.4105 | 132.7922 | up |
| 7.60-8.10 | 0.1324 | 0.2651 | 66.2684 | down |

**Table 1:** This table shows the time periods and results of some calculations to be plotted later.

### 3. Biceps and Triceps

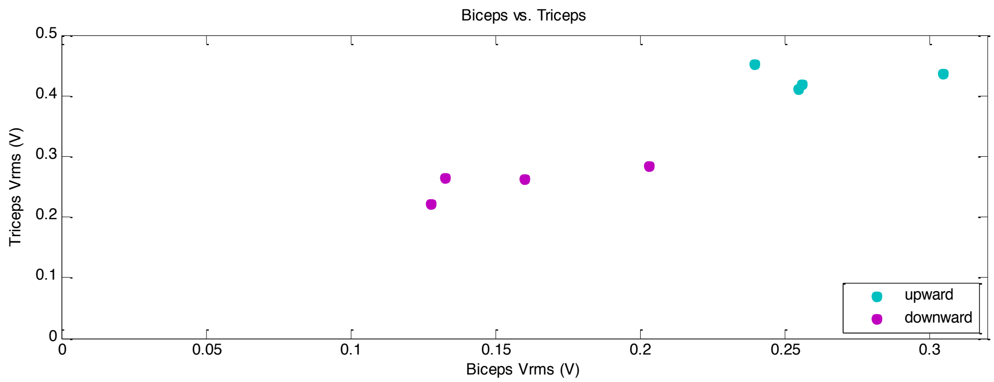


**Figure 10:** The plot shows the relationship between biceps and triceps. The different colors show whether the arm was moving up or down.

In this task, the subject is asked to lift their arm 90° to a target with a weight. Electrical activity data for the biceps ranges from about 0.23V – 0.32V, and for the triceps it was 0.4V – 0.5V. For the lowering of the arm to 90°, the activity ranges from 0.13V – 0.21V for the biceps, and from 0.2V – 0.3V . Each range is about 0.1V, and for the lift task there is more of a difference between the biceps/triceps ranges (about a 0.08V), than during the lowering task (about 0.02). From this particular subject's data, it is seen that more electrical activity takes place within the triceps than within the biceps for both lifting and lowering tasks. This is reasonable because as one muscle is contracting, the other muscle must be less contracted and more relaxed due to their antagonistic relationship.

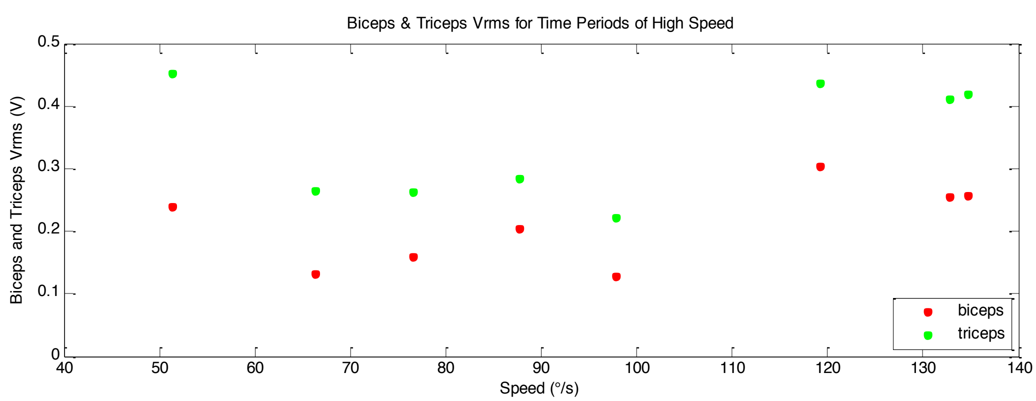


**Figure 11:** The plot shows the relationship between biceps and triceps during time intervals at high speed. The different colors refer to the biceps and triceps separately.

Again, it can be seen that the higher $V_{RMS}$ values of the triceps show that more electrical activity occurs within the triceps compared to the biceps. However, the $V_{RMS}$ of the muscles does not seem to follow any particular trend-line. Instead it just shows the difference of $V_{RMS}$ values between the biceps and triceps over a range of angular speeds from 50°/s – 140°/s. Notice that around 50°/s, this has the largest difference of about 0.25 $V_{RMS}$ whereas, at around 88°/s, this has the lowest difference of about 0.07 $V_{RMS}$. It is expected that there should be large differences because the pairs are antagonistic (one muscle works more while the other is ideally relaxed, hence one $V_{RMS}$ value being significantly higher than the other to depict more electrical activity in one but not the other), but it seems that the muscles at around 88°/s are acting together. This is not expected.

The difference of $V_{RMS}$ values, where one muscle works more than the other is to be expected because these muscles are antagonistic, but there are times when the difference is so small, it's as if the muscles are working at the same time, which was not expected.

## 4. Muscle Fatigue

The power spectral density was found by taking the Fast Fourier Transform (FFT) of the raw EMG bicep and tricep signals and then multiplying the complex conjugate to it.

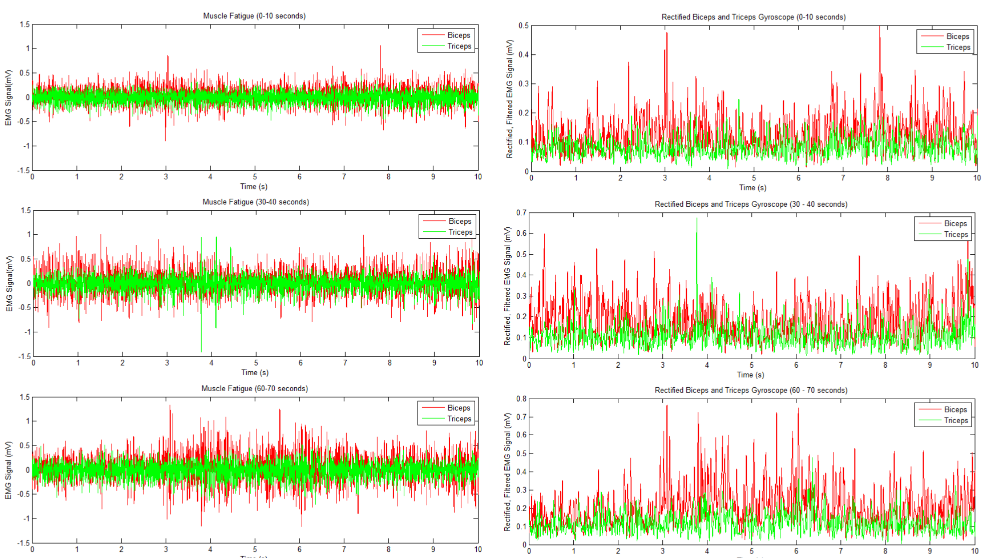


**Figure 12:** (Left) Raw EMG signals of biceps and triceps. (Right) Filtered, Rectified Signal found by running a low pass filter then taking the absolute value of the mean of the EMG signal subtracted from the raw EMG signal in order to quantify the signal.

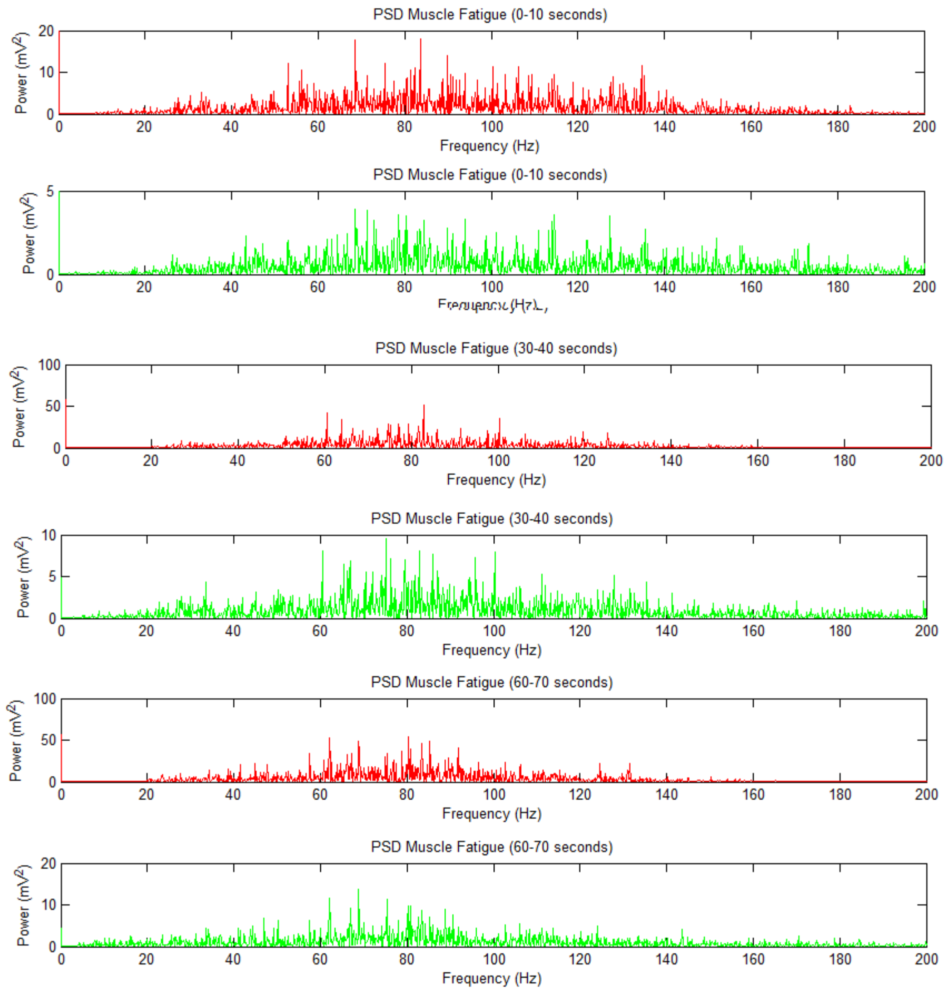


**Figure 13:** Subject 1 Power Spectral Density of each time period. Frequency axis was found for the first half of the time points and the rest are symmetric. Only frequencies 0-200 Hz are shown.

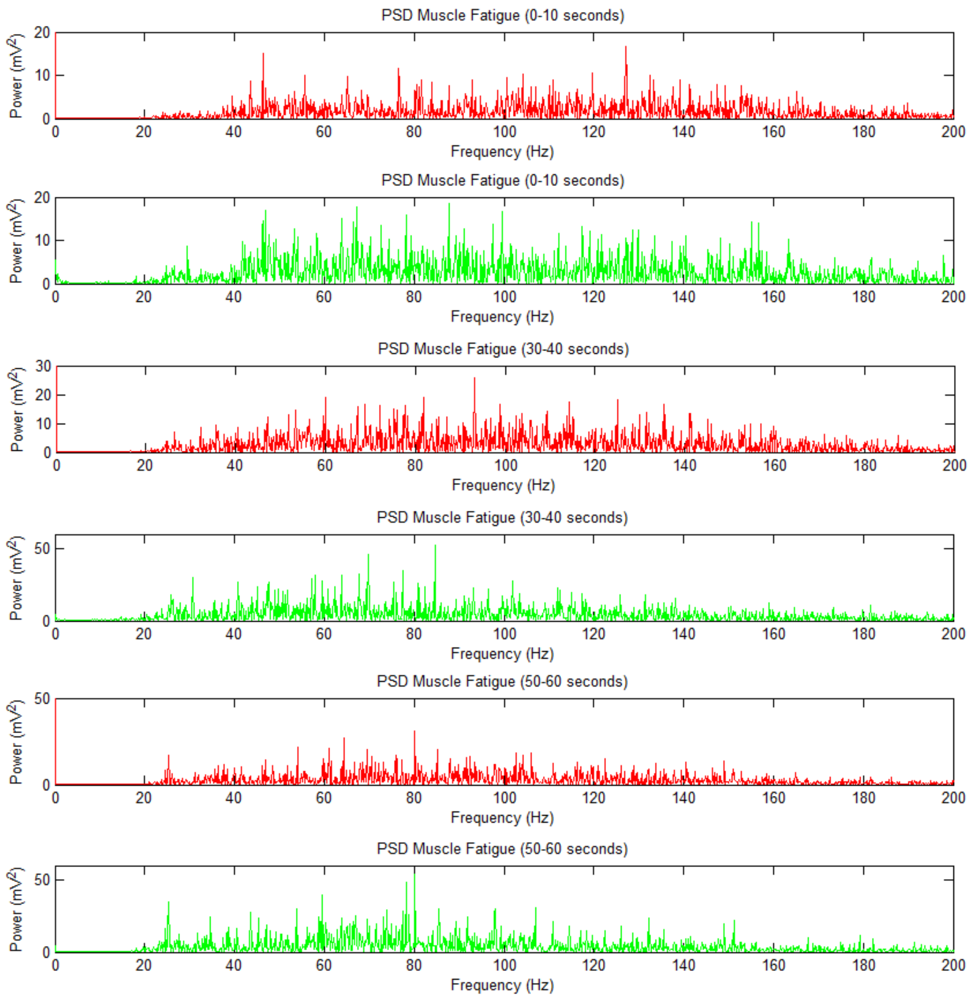


**Figure 14:** Subject 2 (KB) Power Spectral Density of each time period. Across the three time periods when measurements were taken, the motor neurons fire at different frequencies, but within each time period, the biceps and triceps seem to fire together at certain frequencies. Comparing the top plot of Figure 13 to the top plot in this figure, it can be seen that the firing rates do not peak at the same frequencies.

## IV. Discussion

The EMG experiments done in this lab sought to determine further insight about the correlation amongst different skeletal muscles by measuring and analyzing their electrical activity. The three main experiments were: $V_{RMS}$ vs. Torque, Biceps and Triceps, and Muscle Fatigue. For the first two experiments, conclusions were drawn about the relationship between the $V_{RMS}$ and the torque (by alternating the weights), and between the biceps and triceps. The Biceps and Triceps experiment introduced the use of a gyroscope to measure its electrical axis along a given axis (able to measure for the angular velocity) when the arm is rotating (either a lift or lower). Muscle fatigue was observed in order to infer its muscle activity's behavior over time.

For the $V_{RMS}$ vs. Torque experiment, it has been hypothesized and confirmed that the relationship between them is directly proportional. But due to the variation in results (equations obtained: power, exponential, and polynomial at least to the third), it is concluded that there is no global expression which describes the relationship to one another. However, the relationship can be inferred for each subject, for a specified task. Note that although Subject 1 had the same power relationship for both, their trials were not as consistent as the trials of Subject 2. Based on the results of Subject 2 expressing different relationships based on their task (4cm or 6cm), this is what shows that only local behaviors can be described. The data and results do not require anymore information to be concluded because of the limitation of supplies. Notice that for the polynomial expression described the 6cm task done by Subject 2, can only go up to the third order because of the limited x-data. There are only 4 x-values because only 4 weights are used. If more weights are used, then this changes the polynomial behavior (may increase order of polynomial). When reproducing this experiment, time must be allotted, because of length, to allow the subject a rest period for its muscle to be fully in equilibrium before beginning each trial. Also, more subjects and trials must be performed to obtain better inference from observed correlation if time permits. Lastly and most importantly, more weights and a wider range of weights must be used. Only 4 weights with a range of 20 were used. If at least 10 weights were used with a range of 1lbs - 50 lbs then it can be seen if the plot immediately increases like that of an exponential, or if it only maintains a linear regression, or to see if it is of higher order if expressed as a polynomial. A wider range and the number of weights should be taken into consideration when doing this experiment so there is enough data to make better conclusions.

For the biceps and triceps correlation experiment, some results were expected and unexpected. Depending on the time and angle of rotation, based on the results, it shows that the muscles were either contracting together (electrical activity fires together), or not together (doesn't fire together). Because these are antagonistic muscles, it is expected that only one muscle contracts while the other is relaxed; hence, the difference between $V_{RMS}$ values should be significant (one being much higher or lower than the other). It is unusual that the data shows that the muscles are acting together (at around 88. This may be because during the task, the subject's elbow was not stabilized. Stabilization would have allowed one of the muscles to rest, but because there was no place for the elbow to rest, it is possible that the muscles worked together just to stabilize itself by rotating the arm in one axis, instead of just utilizing the muscles to just lift the weight. When reproducing this experiment, stabilization must be taken into consideration because as witnessed here, lack of stabilization disrupts data.

The results from the muscle fatigue experiment display motor firing frequency variance across biceps and triceps motor units. For the most part it is evident that the motor units fire at nondeterministic and unpredictable rates. Variation occurs across trials, but for the most part, within a trial, the subject produced results that showed similar firing frequencies within trials for both muscles. Because we are testing antagonistic pairs in a stationary position, these results help us see how they both work at once. This experiment could produce enhanced results by varying the weights and therefore varying the force since it seemed the firing rates were random. Further experimentation could either confirm this, or prove that there are certain firing frequencies that occur more than others.

## V. References


[1] http://www.sdge.com/power-frequencies

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[4] Purves D, Augustine GJ, Fitzpatrick D, et al., editors. Neuroscience. 2nd edition. Sunderland (MA): Sinauer Associates; 2001. The Motor Unit. http://www.ncbi.nlm.nih.gov/books/NBK10874/

[5] R.A Conwit, D Stashuk, B Tracy, M McHugh, W.F Brown, E.J Metter. The relationship of motor unit size, firing rate and force. http://dx.doi.org/10.1016/S1388-2457(99)00054-1

# Appendix

1. PSD

```
figure
X = tdata;
Y = fft(data,85001);
Pyy = Y.*conj(Y)/85001;
f= 10000/42501*(0:42502);
plot(f(1:1000),Pyy(1:1000));
title('PSD');
xlabel('Frequency (Hz)')
ylabel('Power (mV^2)')
```

2. Data Recorder (code from Jeff Moore)

```
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 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
```

```matlab
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,devicenum);
%------------------------------------------------------------------------%

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
```

3. Rectified, Filtered EMG

```
function emgproc = emgfilter_phys173(emgsignal,Fs);
% inputs:
% emg signal - raw signal
% Fs - sampling frequency

% outputs:
% emgproc - filtered, rectified signal

% integrated amplitude of EMG signal
lowpass_cut = 40; % 80 Hz e.g. berg & kleinfeld, 2003

[b a] = butter(3,lowpass_cut/(Fs/2));
emgproc = filtfilt(b,a,abs(emgsignal-mean(emgsignal)));
```