Tired Fingers

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Question

What is the effect of finger-related tasks of writing, typing and texting on the activity of finger muscle groups?

Research

With recent advances in technology such as personal computers and mobile smartphones, our fingers are being used in a variety of tasks on a daily basis. It is estimated that people type about 2000 keystrokes per hour and text about 5000 characters per day. Students write about 3 pages every day, which is equivalent to 5000 characters. Texting has become widespread among both young and old, while the jobs of technology workers requires them to type on their computer keyboards throughout their workday. Students, from elementary school all the way to graduate school, are now expected to type their reports on a computer, in addition to turning in hand-written reports. These activities can cause significant stress on our fingers resulting in long-term impairment. Some negative effects, such as carpal tunnel syndrome due to typing, are already known. There could be more damage that is yet to be identified. This project aims to study the fatigue induced in finger muscles due to writing, texting and typing. Results of this study can help identify the activities that cause the finger muscles to tire faster, enabling better care for such muscles by adding adequate rest periods in between activities. This research can also motivate the adoption of new ergonomic solutions, such as voice or gestures, to enter information to mobile or computing devices. If this project is extended to explore other muscle groups, it can also help in understanding the different rates at which muscles get tired thereby providing motivation to create techniques to transfer activities to those muscles that are more resilient.

Muscles in our body are bundles of tissue that help us perform any task by contracting. Even within a specific muscle, selected individual bundles can contract depending on the force that is required. This selective contraction of individual bundles occurs when they are activated by nerves attached to them. When we need to perform any task, the brain sends signals through the nerves as action potentials to the respective muscle groups. The action potentials that are transferred from motor neurons to the ends of the muscle tissue travel through the muscle and cause a series of chemical reactions that result in the contraction of the muscle. Our finger movements are controlled by muscles shown in Figures 1 and 2. Of these muscles, the *abductor pollicis brevis* (APB), shown in Figure 1, controls flexion of the thumb, and the *flexor digitorum superficialis* (FDS), shown in Figure 2, controls the flexion of the other four fingers. Since this study explores the activities of writing, typing and texting which need flexion of these muscles, they have been selected for analysis.

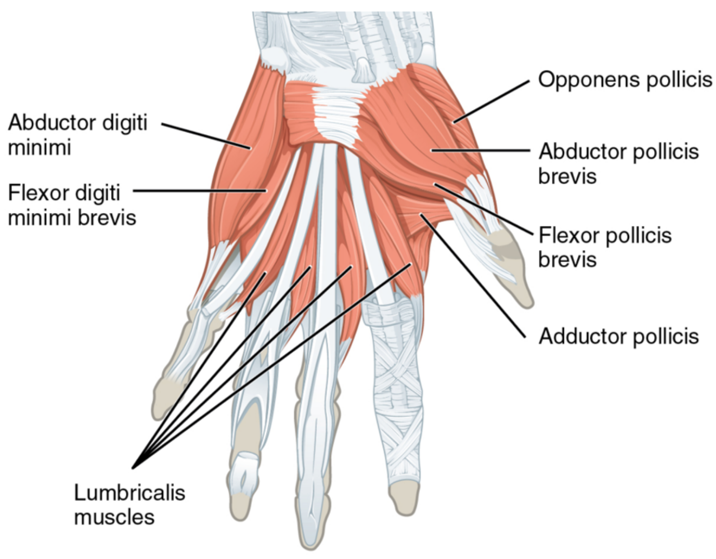

Figure 1. Muscles in the human palm.

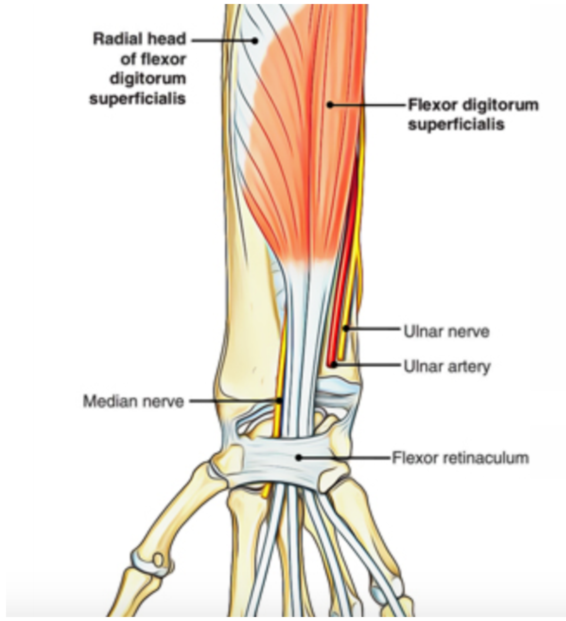

Figure 2. Muscles in the forearm that control flexion of fingers.

One of the methods to measure the performance and fatigue of muscles is electromyography (EMG). EMG captures the action potential that has traveled across a muscle to create the reactions needed to contract the muscle. There are two types of EMG: surface EMG and intramuscular EMG. Surface EMG involves recording muscle activity from the surface above the muscle through electrodes placed on the skin. EMG recordings capture the voltage difference between two separate electrodes placed on the skin along the muscle tissue. Surface EMG are more effective for superficial muscles closer to the skin than those buried deep within the body. The activity captured is influenced by the depth of tissue under the skin and by voltages in neighboring muscles. Intramuscular EMG is intrusive as it involves insertion of needle electrodes into the muscle. The design of such electrodes enables capturing deep muscle activity by restricting the influence of adjacent muscles. However, the activity can still be influenced by those of superficial muscles above the deep muscles. Due to its non-intrusive nature and recent development of inexpensive sensors, surface EMG has been used to capture muscle activity, and this project uses surface EMG.

In order to perform surface EMG on the two selected muscles, the Myoware muscle sensor from Advancer Technologies was selected because of its affordability and its ability to provide raw EMG signals that can be read into a microcontroller such as an Arduino Uno. This sensor can be powered by an Arduino or by an external battery. The embedded electrode connectors on the sensor board allow the board to be stuck onto a separate set of electrodes placed on the skin of a subject at a location on top of the target muscle. The sensor has an on-board circuitry to capture the EMG signal and send this out through a terminal which can be connected by a wire to an analog input port of an Arduino. After the Arduino is connected to a computer using a USB cable, a set of programs written in Python, can be used to collect and analyze data streaming in from the sensor through the Arduino.

Electrical signals are captured using an EMG sensor as a time series of voltages, in which voltages are recorded at discrete time instants from the start of an activity till its end. Usually, at each time instant, an EMG sensor outputs a voltage as a digitized signal within a specified range (say, 0 to 1023). This time series signal is then processed to calculate metrics that can indicate muscle fatigue. Research has shown that muscle activity and fatigue can be measured by two metrics, one based on the amplitude of the signal, and another based on the mean frequency of the signal. Recent studies indicate that fatigue can be measured as an increase in the amplitude or a decrease in the frequency of the signal as the activity proceeds. Measures of amplitude and frequency are calculated for each fixed-length time window that is shifted along the time series of the signal. Figure 3 shows a picture of an EMG signal as time series, and the different time windows of the signal as the window shifts.

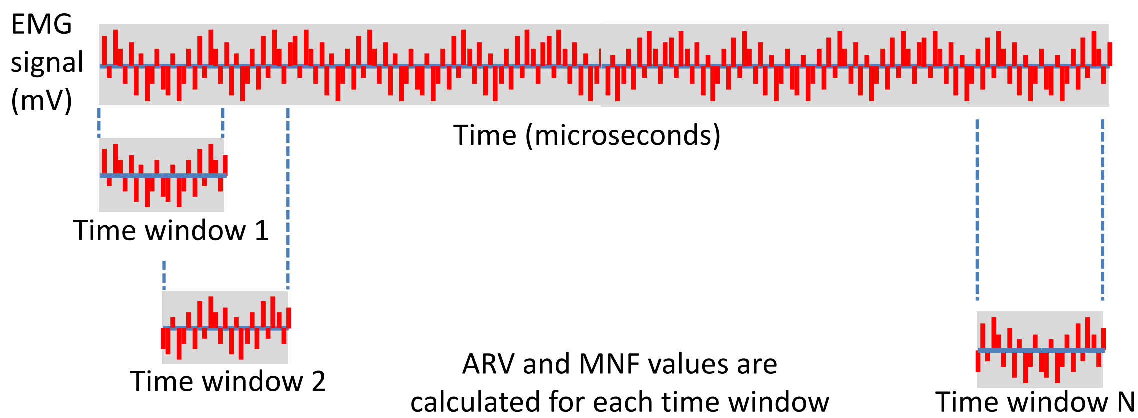

Figure 3. EMG signal and the different time windows used for processing.

For each time window, the Average Rectified Value (ARV) is calculated as a measure of the amplitude. The ARV value for a window is calculated as the average of the absolute values of the signal over all time points in the window. For calculating the mean frequency, first each frequency component, f_i, and its corresponding amplitude, Y_i, of the signal values in the time window are computed using the Fast Fourier Transform (FFT). The mean frequency, MNF, is then calculated as $\frac{\sum_i f_i Y_i^2}{\sum_i Y_i^2}$. For each window, the ratio of MNF to ARV is calculated as an indication of muscle response. The gradient of MNF/ARV over time is called the **fatigue metric** and has been proposed in the literature as a metric to measure muscle fatigue. The more negative this fatigue metric, the more the fatigue of the muscle. For this experiment, the calculations above and the metric computations are performed on the time series data and stored in different files using Python programs written to extract this information.

One thing to note is that usually the EMG data coming from the sensor is not uniformly spaced in time, and the time series data needs to be interpolated in order to obtain an evenly spaced time series data. This is needed since the FFT packages available commonly as Python functions to extract the frequency spectrum require the input series to be uniformly spaced in time. Also, the incoming sensor data can have noise in both the high frequency and low frequency regions. Since surface EMG signals are known to be in the range of 20Hz to 200Hz, a bandpass filter needs to be used to filter out the noise to clean the signal. The interpolation and the bandpass filtering can be achieved using Python functions. This project interpolates and filters the data using Python programs written with these functions.

Hypothesis

If the duration of the task is increased, the writing task will be the most tiresome for the finger muscles because of the significant pressure and flexion needed to hold a pencil and mark the paper.

Scientific principles and reasoning

The writing task is expected to cause the most fatigue in the finger muscles because only two fingers are involved in this task and those two fingers need to exert considerable pressure to hold the pencil and mark the paper. The next strenuous task is texting as it involves only one finger, the thumb. It has to move around to touch all keys on a smartphone keyboard. However, the thumb does not have to grip the phone, and the force required to type is not high since it only needs to tap on a touchscreen. Compared to the above two tasks, typing on a computer keyboard is expected to be the least strenuous, as less pressure is needed to press keys on the keyboard.

Setup

Figure 4 is a description of the parts of the Myoware sensor.

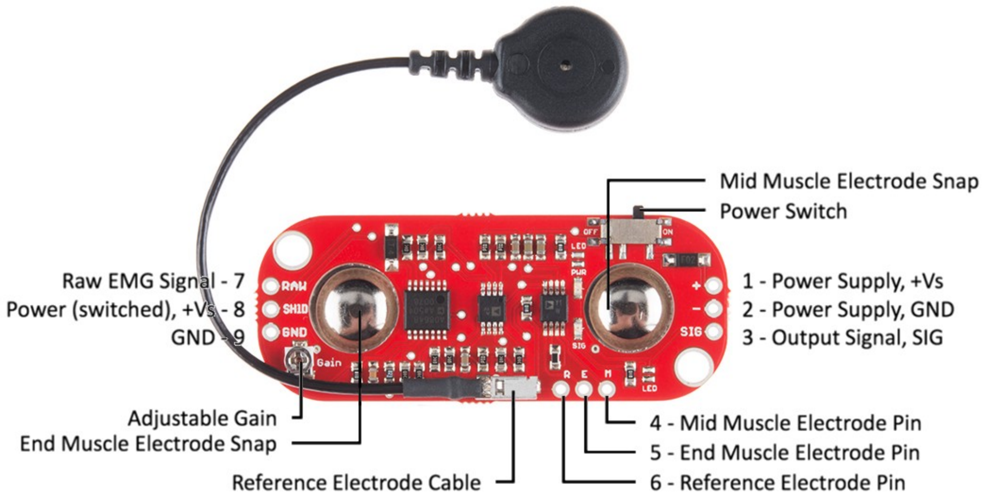

Figure 4. Myoware Sensor.

Figure 5 shows the placement of the Myoware sensor on the subject's arm.

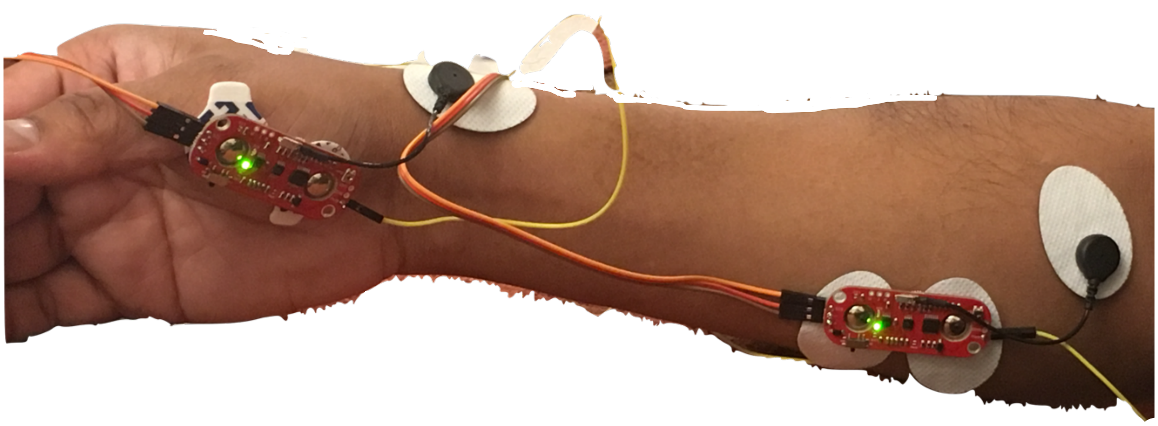

Figure 5. Setup of sensors

The connections from a Myoware sensor to the Arduino and from the Arduino to the computer are shown below in Figure 6. In the Myoware sensor, the two connectors attach to the electrodes, which are pasted on the skin above the area of the selected muscle. The reference connector is attached to an electrode placed far from the muscle.

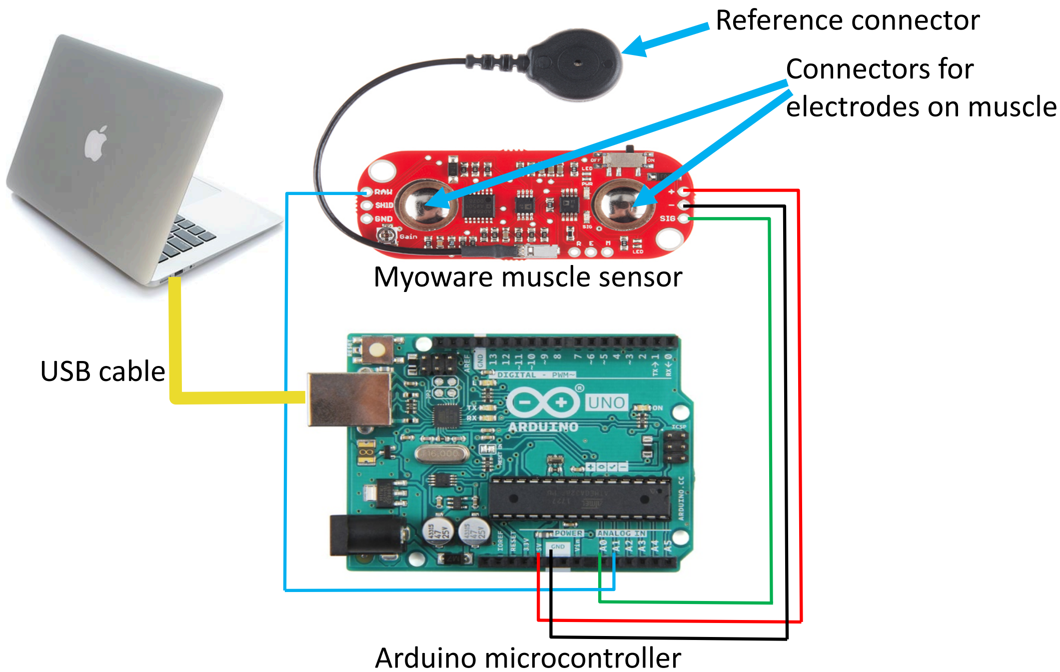

Figure 6. Schematic of apparatus

Materials

The following materials were used for this experiment:

- Keyboard
- Writing utensil (#2 wooden pencil) and paper
- Mobile phone (Iphone SE)
- 2 Myoware muscle sensors
- A pack of 3 dozen electrodes
- Isopropyl alcohol and cotton
- 1 Arduino Uno to receive sensor data on muscle activity

- Jumper wires (male to male, male to female) to connect the two EMG sensor RAW output terminals to the Arduino's analog ports, and to connect the power and ground terminals of the sensor to those of the Arduino
- Serial USB cable to connect Arduino to computer
- A Macbook Pro computer
- An Arduino program created to read measurements, a Python program written to store the measurements in a file on the computer, and Python programs created to process the measurements for results
- 4 test subjects: Male aged 13, female aged 16, female aged 45, and a male aged 48, and their tested muscle groups - abductor pollicis brevis (APB) and flexor digitorum superficialis (FDS)

Methods

The two muscle groups of the fingers, the *abductor pollicis brevis* (APB) and the *flexor digitorum superficialis* (FDS), are tested for each subject. After attaching the sensors to the test subject (as described below), each subject is given a document, containing an excerpt from *The Adventures of Huckleberry Finn*, and is asked to perform the following tasks: (1) hand write the document text on paper, (2) type the document text in an editor on a mobile touchscreen device, and (3) type the document text using a desktop keyboard. Each task is performed for 10 minutes with 3 trials at different times of the day. The procedure below should be repeated for each test subject.

1. Designate one sensor for APB and another for FDS. Using jumper wires, connect the RAW signal terminal from the APB sensor to one of the analog read ports of the Arduino, and connect the RAW signal terminal from the FDS sensor to another analog read port of the

Arduino. Also connect the power and ground connections of the sensor to the Arduino as shown in Figure 6.

2. Connect the Arduino to the computer using the USB cable.
3. Clean the areas of the skin above the APB (near thumb) and FDS (forearm) muscles with alcohol and cotton.
4. For each muscle group, paste two electrodes along the muscle, and a third electrode just a couple of inches away from that muscle group.
5. Connect one Myoware muscle sensor each to the electrodes placed along the two muscle groups by attaching the connectors beneath the sensor board to those electrodes, and attaching the reference connectors to the electrodes placed away from the respective muscle groups. For reference, please see Figure 5 for the location of the identified muscle groups (forearm and thumb) and how to attach the sensor connectors to the electrodes.
6. The subject then starts to write for 10 minutes from the document. At the start of the writing, run the Arduino program, written to receive the sensor values at its two analog ports, and the Python program, written to record this data for both the muscles into a file on the computer, simultaneously.
7. Repeat step 6 for trials.
8. Repeat steps 1 through 7 two more times for the activities of typing on a keyboard and typing on a mobile touchscreen device.
9. Repeat steps 1 through 8 for each of the other 3 subjects.
10. Using the Python programs, compute the Average Rectified Value (ARV), the Mean Frequency (MNF), and the ratio MNF/ARV for a sequence of time windows. Calculate the

gradient of MNF/ARV across these windows, for each task and muscle group for each of the subjects. Compute the average gradient over three trials for each case.

Variables and Groups

Independent variable:

a. The tasks: writing on a sheet of paper with a pencil, texting with a thumb on a touchscreen, typing on a computer keyboard

b. Time for each task

Experimental groups: the value of MNF/ARV at the end of each task

Control group: the value of MNF/ARV at the beginning of each task

Dependent variables:

The fatigue metric, or gradient of MNF/ARV, across time windows

Constants:

- Materials
  - Computer keyboard (Dell desktop keyboard)
  - Writing instrument (No. 2 pencil)
  - Mobile phone for texting (Iphone SE)
  - Muscle groups tested (*abductor pollicis brevis*, *flexor digitorum superficialis*)
  - EMG sensors (Myoware) and microcontroller used (Arduino Uno) to measure muscle activity
- Environmental conditions
  - Location without electrical devices to conduct experiment (electrical devices send out low-frequency electromagnetic waves which can add noise to the EMG signal readings)

Challenges overcome

One challenge was determining the precise location to place the electrodes so that the Myoware sensor can read the activity from the specific muscle. This was overcome by reviewing human physiology articles and pictures on the location of the muscles. Another challenge encountered was ensuring that the jumper wires and the Myoware sensor are properly connected. Soldering was required for contact between the sensor and the wires. This project needed extensive Python programming, especially with new functions to remove noise from the signal and to extract the frequencies. Initially, there were mistakes in the programs for processing the raw EMG signal files. It took much time and effort to fix all the errors.

Data

The data from the raw terminals of the Myoware sensors placed on the APB and FDS muscle groups is recorded in text files. The data from each sensor is received approximately once every 2400 microseconds, and the data is recorded as a time series in a file in which each line has a pair of values: a time instant value, and a signal value. The signal values range between 0 and 1023 at each time instant. A total of 48 time series data from the sensors is recorded (4 subjects x 2 muscle groups x 3 trials x 3 tasks = 72 time series). Each file contains a series that has about 250000 samples (or time-value pairs, one per line). An example of the data that is collected on a subject is shown in Figure 7.

Results and their discussion are included in the slides accompanying this report.

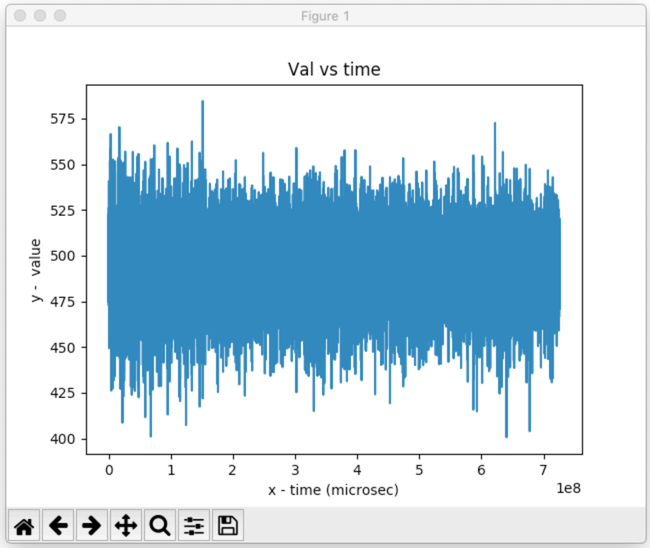

Figure 7. An example of sensor data from a test subject.

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