Identifying Fatigue in the Vastus Lateralis Muscle in Athletes Recovering from Knee Injury

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Abstract

In an attempt to return to exercise or sports after an injury, athletes often overdo rehabilitation. Because of this, there is a possibility of athletes further damaging their recovering muscles or joints. There are current research and projects that note when the muscle reached a state of fatigue based on root mean square (RMS) and median frequency (MF) of muscle EMG measurements after the athlete completed their rehabilitation exercises. This project describes a knee brace device to provide live biofeedback that notes when the athlete's muscle is fatigued during the exercises. The device takes baseline fresh muscle and fatigued muscle measurements to set a fatigue threshold for each unique user. . The knee brace then uses EMG voltage and peak detection in real time to note when the muscle is fatigued. When tested, the device successfully noted when muscle fatigue was reached when compared to the raw EMGs of the test subject.

1.0 Introduction

As an athlete who has had to recover from many injuries, I understand the overwhelming need to return my sport. Like many other athletes, I have been guilty of playing the pain and returning to my sport sooner than was recommended. The problem with going back to a sport or exercising to soon after injury is the possibility of the athletes further injuring themselves.

In an effort to shorten their rehabilitation period and improve their injury faster, athletes over do physical rehabilitation. There is a misconception that more rehabilitation will lead to a faster recovery, so atheltes perform their rehabilitation exercises longer than necessary (Hilliard, Robert C, et al, 2017). As a result, the athletes overuse their recovering muscles and can cause more damage to their injuries by tearing the damaged ligaments more or by halting the recovery progress. "Training errors, specifically those of excessive intensity and duration, represent the principal risk factors for injury." (Crockett, 2011), so it is extremely important to note when an athlete should stop their rehab protocol for that day in order to prevent further injury.

In the study *A Muscle Fatigue Monitor Based on the Surface Electromyography Signals and Frequency Analysis (*Gutiérrez, Cardiel, and Hernández, 2016), the authors created a way to monitor when muscle fatigue is present. EMG signal processing was used to determine when the median frequency shifted and the root mean square value of the amplitude was measured within the time domain in order to determine when the muscle is fatigued. The user performs exercises, while the device records the EMGs. After the exercises are completed, the stored data is used to calculate median frequency and root mean square by using algorithms programmed in LabVIEW. The muscle was determined to be fatigued when the value of the median frequency decreases, while the root mean square values increase, meaning the frequency of signals of surface EMGs (sEMGs) decreased, but the amplitudes of the signals increased, reflecting the overexertion of the muscle.

The device discussed in this paper will focus on live fatigue feedback rather than storing data and analyzing it after the rehabilitation exercises are complete. This device will use electromyography and LEDs as a live warning system for muscle fatigue. The device looks at the voltage output of the muscles to determine when muscle fatigue was reached in the vastus lateralis muscle, which is on the outer side of the thigh. The device will be administered by a physical therapist; the physical therapist will oversee the exercises, make sure the athlete stops when fatigue is noted, perform the baseline tests, and place the sEMGs on the patient.

2.0 Methods

For the muscle fatigue detecting knee brace, the materials needed were a soft neoprene knee brace, MyoWare muscle sensor, a LED, velcro, and Arduino Uno. Velcro was used to attach the Arduino to the knee brace. A function generator was also used to simulate an EMG signal and validate the software algorithms. The function generator generates electric waveforms over a wide range of frequencies. Tthe frequency and amplitude of the waveforms created by the function generator allowed for the validation of the root mean squares and median frequencies calculated by the code. The Arduino program was used to write and develop the code. A MyoWare muscle sensor is an electromyography (EMG) sensor used to measure the electrical activity of the vastus lateralis. The sensor utilizes the attachment of surface EMG sensors in order to measure the electrical signals of muscles. Ultrasound transmission gel was used to strengthen the signal measurement of the EMGs.

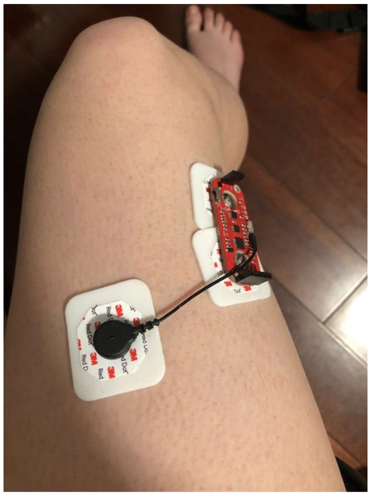


Figure 1: Placement of MyoWare and sEMGs on vastus lateralis muscle

The device will be conceived in two phases. Phase one is a proof of concept by using average peak amplitudes, while phase two integrates the MF and RMS calculations into the peak detection code. Phase two is an enhanced fatigue detection.

2.1 Phase One

For the first phase, the fatigue detection will be based on the average voltage output (AOV), which will be explained later, of the peak amplitudes of 5 waves on an EMG signal. The user will complete a calibration in order to set a baseline amplitude for a non-fatigued (fresh) muscle and a fatigued muscle in order to set a threshold (Galen et al., 2015). Peak amplitude of 5 successive waves are recorded and averaged. Fatigue will be noted if the AOV exceeds the fatigue threshold of the user noted in the calibration phase. The device flow chart below illustrates phase one.

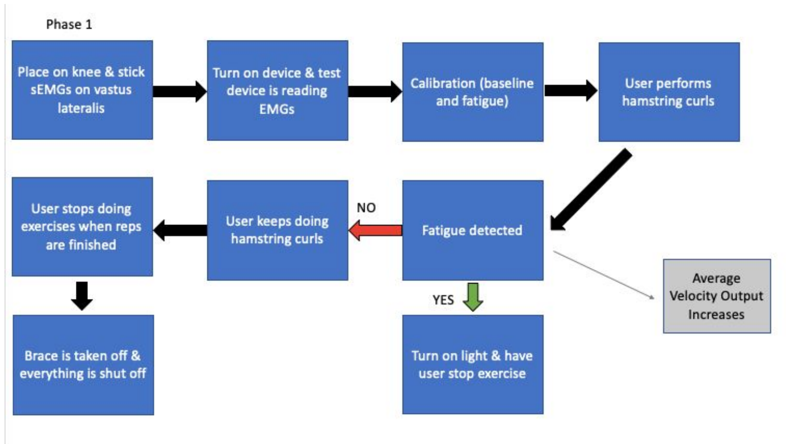


Figure 2: Device flow chart of phase one of the project

2.2 Phase Two

For phase 2, in order to detect muscle fatigue, root mean squares and median frequencies of EMG signals can be used. The Arduino Running Median library developed by Rob Tillaart was used for the median frequency detection part of the code. The interrupt code was provided by Amanda Ghassaei. The root mean square code was originally developed by Leslee Cuenca, but later modified to work specifically for this project. The EMG signals were acquired utilizing Arduono interrupts to allow for a wave sampling rate of 38.5 kHz. Before sending digital output or frequency values to the loops that generate the RMS and MF values, interrupts are used to make sure data is calculated in equal periods. The interrupts measure frequency at a sampling rate of 38.5 kilohertz. The software detects the number of waves measured from the EMG by calculating how many times the signal passed the midpoint of the bit number. Once the period was established, the data collected in that period was sent to two different loops to calculate RMS and MF. Within loops, RMS and MF were calculated and displayed on a serial monitor. The RMS and MF were observable in a live feed. An LED was then used to notify when muscle fatigue was detected (RMS increase and MF decreases), which was determined by using the calibration process mentioned in phase one (refer to figure 2).

2.3 Hardware

For hardware, a soft knee brace was used as the base product for the design because of the flexibility of the material. The Arduino was placed on the knee brace by using velcro. Wire attaches the MyoWare sensor to the Arduino and is placed so that the surface EMG sensors can be attached to the vastus lateralis muscle, the largest muscle that helps control the knee joint . The Myoware sensor is connected to the Arduino through wires, and the surface EMG sensors connect the MyoWare to the skin above the vastus lateralis muscle. The LED that notifies when muscle fatigue is detected is placed where the knee brace covers the thigh in order to make it visible to the user.

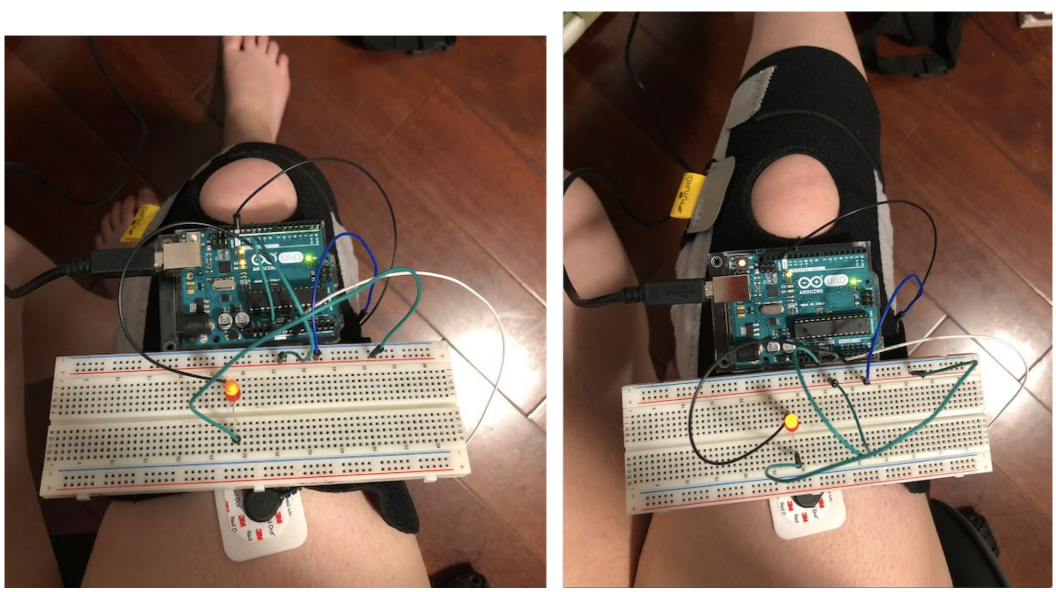


Figure 3: Physical knee brace on user

2.4 Validation

For validation, the raw EMGs of an user were measured while the user was performing hamstring curls. The EMGs of the user were observed in order to determine the relative amount of time and reps it takes for the vastus lateralis muscle of the user to fatigue. Fatigue can be noted by looking at the amplitudes and frequencies of the EMG (Kim, Lee, Kim, 2018). The user then repeats the hamstring curl reps, but now the RMS and MF were observed. The values of the AOV or RMS and MF were observed to note if those values identify muscle fatigue at around the same time as the raw EMGs did.

3.0 Results

After completing the baseline tests, the device was able to detect fatigue in the vastus lateralis. Since the test subject of the knee brace was not recovering from an injury, fatigue was induced by having the subject hold their leg up while having weight placed on the leg in order to induce the fatigue faster than if the subject solely did hamstring curls. To verify that the brace worked, raw EMGs were taken of a vastus lateralis when it was fresh and when it was fatigued.

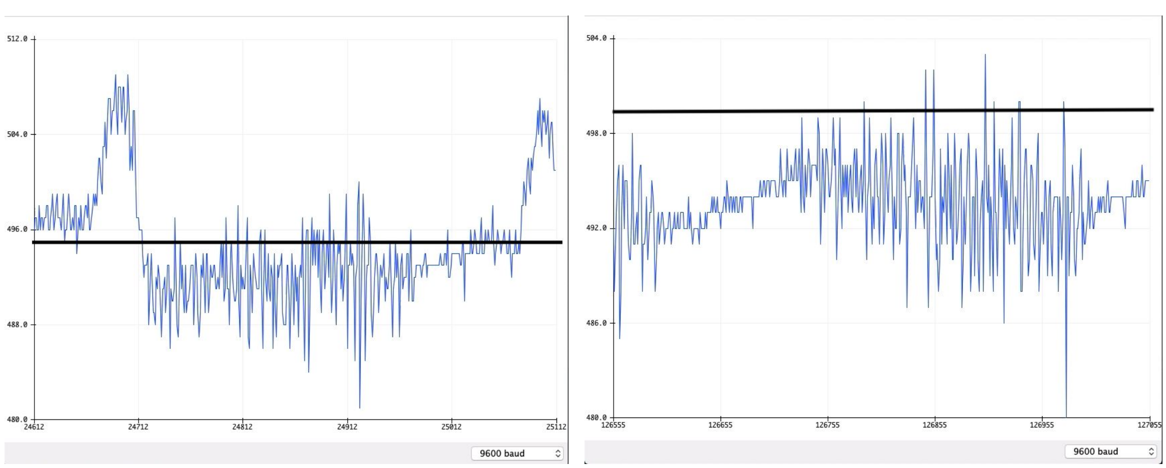
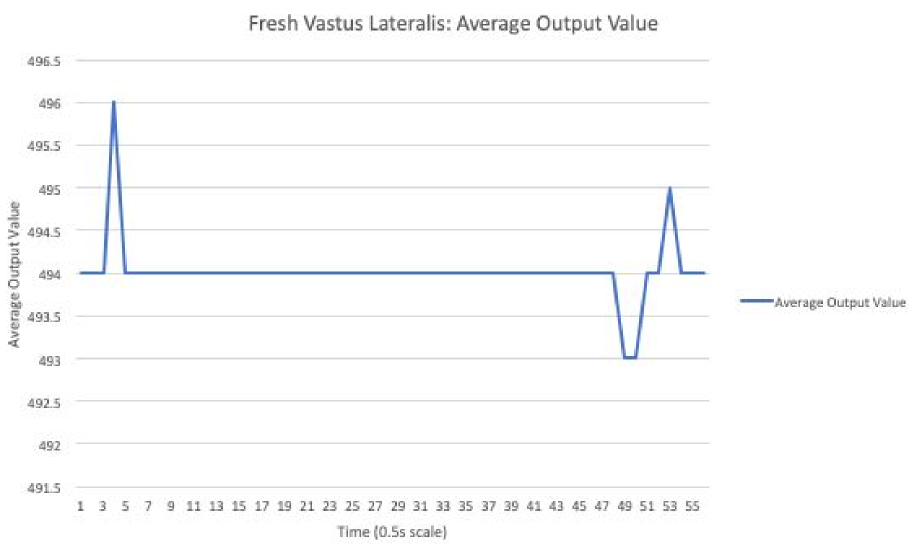
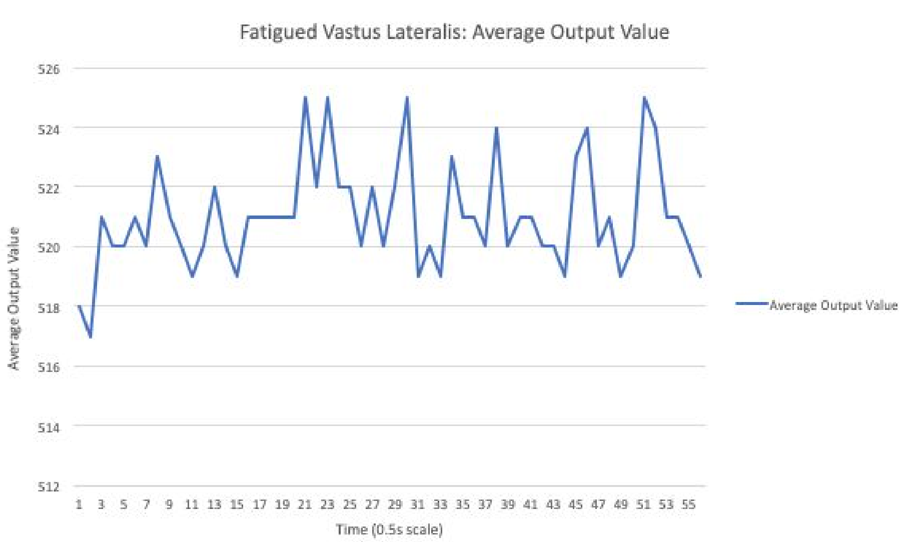


Figure 4: Fresh muscle EMG on the left and fatigued muscle EMG on the right

The images of the two EMGs above show the difference between a fresh and fatigued muscle. The fatigued muscle output higher voltage values, which denotes higher amplitudes of the waves, than the fresh muscle, which matches up with the trend of fatigued muscles. The fresh muscle shows a constant AIV because the muscle is at rest, so there is no change to the muscle activity because it is not flexing.



Graph 1: Fresh muscle AOV



Graph 2: Fatigue muscle AOV

The graphs above show the difference between the AOVs of a fresh and fatigued muscle. The fresh muscle tended to output an average value of the five peaks at around 494, while the fatigued muscle tended to output an average value of the five peaks at around 520. After these baselines were observed, the code was modified so that once the live AOV reached a value of around 98% of the baseline fatigued AOV, the LED turned on. A slightly lower value of the baseline fatigue AOV was used to ensure the user is notified before fatigue is completely reached in order to reduce the negative effects of exercising with a fatigued muscle.

When observing the raw EMGs and the AOV, the times it took to fatigue the muscle were noted. In both cases, fatigue was reached after about 1 minute and 30 seconds. The fatigue was reached quickly since the test subject held her leg up with added weight, which is more strenuous on the leg muscles than hamstring curls.

4.0 Discussion

4.1 Results Discussion

The validation of phase one shows that live feedback for muscle fatigue was achievable using the device I have presented. Fatigue was able to be detected during a live exercise, which has not been achieved by other researchers, since the researched fatigue detectors relied on analyzing the data after the exercise. The live feedback will allow athletes to stop performing their rehab exercises if their muscles need a break. By doing this, athletes may be able to return to their sport or exercising faster since they will not be hurting their injured knee more when going through rehab.

4.2 Limitations

The limitations of this project is due to the processing power of the Arduino, processing time, and conductivity of the sensor EMGs. If interrupts are not used, then the Arduino is not reliable to detect all of the peaks in order to set data sets that can be used to then calculate RMS and MF. This specific project is also limited by the conductivity of the sensor EMGs. These sensors were not consistently providing a secure connection between the muscle and the MyoWare.. Another limitation is who the user is. It is best that the rehab process using this brace is observed by a professional to ensure the user listens to the product. The physical therapist would oversee the exercise to make sure the user is performing it correctly and would place the sEMGs on the correct place on the patient.

4.4 Future Improvements

For future renditions it is suggested implementing interrupts and the MF and RMS calculations. By using the MF and RMS values to note when muscle fatigue is detected, the knee brace will be more accurate as RMS and MF are better notifiers of fatigue, as stated in the beginning of the paper. To integrate the interrupts, there is further research and a need for acquisition of knowledge of how interrupts work. Encoders can be implemented as an enhancement so as to measure the angle of the hamstring curls in order to ensure the user is performing the exercises correctly. The encoders would be used to make sure the user reaches 90 degrees when performing the hamstring curls.

For hardware improvements I would suggest implementing the device into a smaller, more user friendly model in order to make the device more portable. This can be achieved by using an Arduino Nano and by sewing the device onto the knee brace. Also, instead of connecting the Arduino to the computer by USB cable, a battery can be used, so that the user's movement is not limited by a USB cable. I also recommend using a knee brace that is a neoprene sleeve that does not have straps in order to ensure the knee brace doesn't slip down as easily.

There is also room for improvement for the process for setting the baseline for fresh and fatigued muscle. The ultimate goal is to get rid of the calibration stage, so that there is not more strain on the injured knee. In order to determine when the threshold at which fatigue is reached, more testing and research for fatigue trends should be conducted.

5.0 Conclusion

A knee brace device was developed to detect muscle EMG signals and use those measurements to determine muscle fatigue. The device successfully detected fatigue consistent with fatigue indicators from raw EMG when comparing the amount of time it took the test subject's muscle to become fatigued. Based on fatigue detection, immediate feedback is given to the user, so the user can stop the rehabilitation exercises before too much damage is done. There are further improvements for the knee brace to make it more user friendly and accurate when notifying fatigue. Overall, the knee brace worked at noting fatigue based on average voltage output.

6.0 Works Cited, References, and Acknowledgements

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7.0 Appendices

Device/Software User Manual:

https://drive.google.com/open?id=19eVaH6R811PC6_WAaP8CjbZ1WXR-MNlwHKI3jAiUj_8

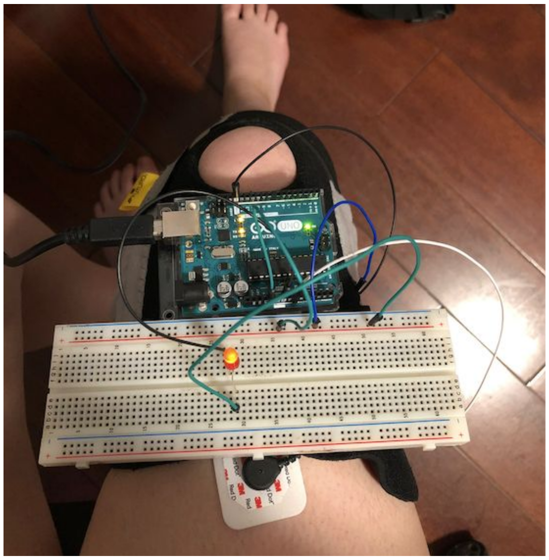
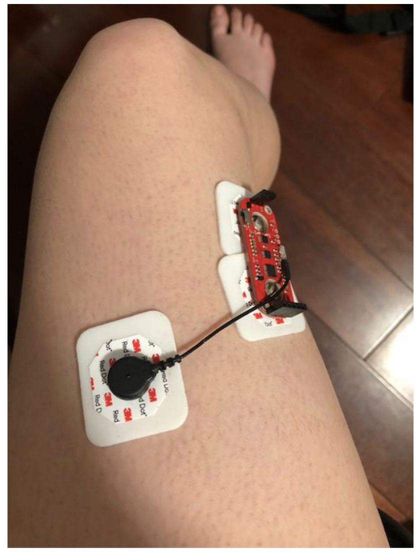
Average Voltage Output Value Code:

https://drive.google.com/open?id=1itssPSFg7vdu0sGQ7jyU-qJ2GmHJcxNF

Interrupt, RMS, and MF Code:

https://drive.google.com/open?id=1M8oAxIEu0tja-y5XS7htdz0r8VTSUwo-

Photo Documentation of project:

Project Journal:

https://drive.google.com/open?id=1IJfsfAlw5jY3rj6xwzHVzXdwAvruoUNxfkoqWvxe0
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Original Proposal:

https://drive.google.com/open?id=1V94Z8R4on0PCkvvqXnWs406Kj-gxtps5tDbiUqxvB
Eo