BMEG 201 | Group 7 | Project Report

To: Sukhneet K. Dhillon
From: Aly Khan Nuruddin, DongWoo Han, & Raymond Hubscher
Date: March 08, 2022
Subject: Methodology for Quantifying the Effects of Muscle Fatigue Caused by Electromyostimulation

Table of Content

Figures

A. Summary

This research project investigates the relationship between the duration of EMS performance and the level of muscle fatigue made by EMS. The data is collected by performing electromyography with the BioCapture software system. We generated two types of graphs, EMG FFT to examine the frequency shift of action potential due to muscle fatigue, and EMG and time graph to evaluate the amplitude of EMG with respect to time. A force-time was additionally made to further analyze MVC force produced due to EMS activity. Analysis of both the EMG-FFT and EMG-time graphs revealed a positive relationship between muscle fatigue and EMS duration.

B. Introduction

Electromyostimulation (EMS) is a method of exciting motor neurons by sending electricity from an external device which will cause motor-unit-action-potential (MUAP), thus stimulating muscles. Muscle contraction caused by EMS is then an involuntary contraction that is not initiated by the central nervous system. This method is widely used as a treatment in musculoskeletal system of \ the recipient without performing a voluntary physical movement. Because of the idea of stimulating involuntary muscle contraction, EMS is one of the most promising solutions for individuals whose mobility is entirely or conditionally restricted.

Typical usage of EMS can be found in the sports field and multiple clinical areas such as sports science, kinesiology (physiotherapy), rehabilitation medicine, neuro medical fields. In order to effectively utilize EMS in clinical or fitness areas, we must identify how the parameters of EMS signals (duration and intensity) affect the effectiveness in inducing muscle fatigue (or "exercising-effect"). Our research project primarily focuses on finding the relationship between the duration of EMS performance and the level of muscle fatigue. Furthermore, our team is intending to investigate the different parameters in the electric signals of EMS, (voltage, controlled pattern in current flow, etc).

Therefore, our team would like to propose this research project to investigate EMS's property, behavior, and performance and its electric signal in multiple conditions (controlled conditions/environment), which can be commonly found in the clinical field, and discover a more advanced method of processing and evaluating EMS signals and data. This research aims to make discoveries that can potentially provide an idea to develop a further novel application of EMS in clinical fields, which overcomes the current limitations.

C. Alternative Solutions

Methods of decreasing skeletal muscle inflammation and fatigue have been the use of low-level laser therapy (LLLT) (Mantineo, Pinheiro, Morgado, 2014) and light emitting diode clusters (Leal, Lopes-Martins, Rossi, De Marchi, Baroni, de Godoi, Marcos, Ramos, Bjordal, 2009). Both methods were successful at reducing the muscular inflammation in the test subjects. Of these previous methods, the light emitting diode therapy (LEDT) has been shown to slightly delay skeletal muscle fatigue and decrease the formation of exercise by-products, such as lactate.

Therapy	Equipment Cost (USD)	Price for Patients (USD)
Low Level Laser Therapy	1000 - 10,000	60 - 250 (Dynamic Wellness, 2018)
Light Emitting Diode	350 - 4,400 (Platinum LED Therapy Lights)	25 - 200* (Platinum LED Therapy Lights, 2021)

*Cost for treatment of skin. Costs of treatment of muscle was not available.

Table I: Costs of Alternative Therapies for Skeletal Muscle Inflammation & Fatigue.

As can be seen in Table I, the costs of a light emitting diode machine is generally less than for a low level laser system. This, and the demonstrated effectiveness on achieving the desired therapeutic effects, makes LEDT the more attractive of these two alternatives to the proposed approach.

D. Design

I. Overview

To quantitatively ascertain the effectiveness of electromyostimulation, we attempted to strain the forearm muscles between rested and active phases. The *bicep* and *tricep* muscles were determined to be an ideal, complementary muscle pair for our experiment given their ease of accessibility, superficial *subcutaneous tissue* mass, and simplistic, *flexion-extension* movement. Interference from other muscles were therefore minimized, and did not significantly hamper the quality of the data sourced.

Hence, the hypothesis for our investigation is underlined as follows; the time during which the muscle group is subjected to electromyostimulation is inversely dependent on the peak frequency of muscular contraction. Provided this relation holds true, it can then be concluded that electromyostimulation can effectively be utilized as a therapeutic device to enhance strength.

II. Evaluation Methodology

Electromyostimulation of the forearm was conducted following adherence to sanitary protocol, where any exposed surfaces were cleansed with alcohol swab, and electrode gel. Next, 2 stimulus-delivering electrodes were placed on the contact surface, along the intersection of the digitorum profundus and pollicis longus flexor muscles, and on the pronator quadratus. Similarly, 3 recording electrodes were placed on the contact surface, 2 of which were localized 1 - 2 cm, distally, from the stimulus-delivering electrodes, while the grounding electrode was externalized on the olecranal skin.

Each trial consisted of the subject actively utilizing the machine for 10 minutes, performing 444 contractions at a set intensity. Next, recording electrodes were connected to *BioCapture*, a data acquisition interface for processing electromyogram data generated through the forearm muscles. Subsequently, the recording electrodes were disconnected and stimulus-delivering electrodes were coupled to the electromyostimulation machine.

Following 3 days of minimal physical activity, the participants were subjected to electromyostimulation, to obtain the required data. Subject I underwent 3 trials of the same intensity, with short breaks of 5 minutes in between. Meanwhile, Subject II participated in 3 trials at increasing intensities, with a prolonged rest period of 30 minutes in between.

E. Data Analysis

Stochastic interpretation of the synthesized data was conducted using MATLAB. Fast-Fourier Transforms of the frequency spectrums were subjected to a *band-pass filter*, of 100 Hz and 300 Hz, respectively, providing peak frequency values, as mentioned below:

(Hz)	Control	T1	T2	T3	CNS Peak
S1	53.11	52.65	51.76	50.32	47.86
S2	68.46	60.015	58.53	54.33	49.72

Table 2: Peak Frequency with Increasing Electromyostimulation Intensity.

Further, linearized envelopes of electromyogram data were analyzed via *LoggerPro*, providing the maximal and mean voltages during electromyostimulation, as mentioned below:

	Before EMS Activity (V)	After EMS Activity (V)	CNS Exhaustion
S1: Max Voltage	0.145586	0.110008	0.105622
S1: Mean Voltage	0.104063	0.072312	0.065342
S2: Max Voltage	0.100464	0.074181	0.059842
S2: Mean Voltage	0.081698	0.060669	0.048765

Table 3: Changes in Maximal and Mean Voltages Before & After Electromyostimulation Activity.

Lastly, force-time data was methodically examined via *LoggerPro*, providing the maximal and mean forces generated during electromyostimulation, as mentioned below:

	Before EMS Activity (N)	After EMS Activity (V)	CNS Exhaustion
S1: Max Force	153.51	145.76	141.6
S1: Mean Force	134.89	126.14	129.4
S2: Max Force	177.89	161.75	163.5
S2: Mean Force	164.81	150.73	154.4

Table 4: Changes in Maximal and Mean Forces Before & After Electromyostimulation Activity.

F. Testing Results

Table 2 demonstrates a decline in peak frequency with an increase in the activity and duration of electromyostimulation. Meanwhile, *Table 3* depicts a decrease in mean and maximal voltages, following electromyostimulation activity in both subjects. Additionally, *Table 4* denotes a decrease in mean and maximal forces, following muscular contraction.

Hence, a comparative analysis of these values to those required for muscular fatigue was conducted to determine the effectiveness of electromyostimulation activity, as indicated below:

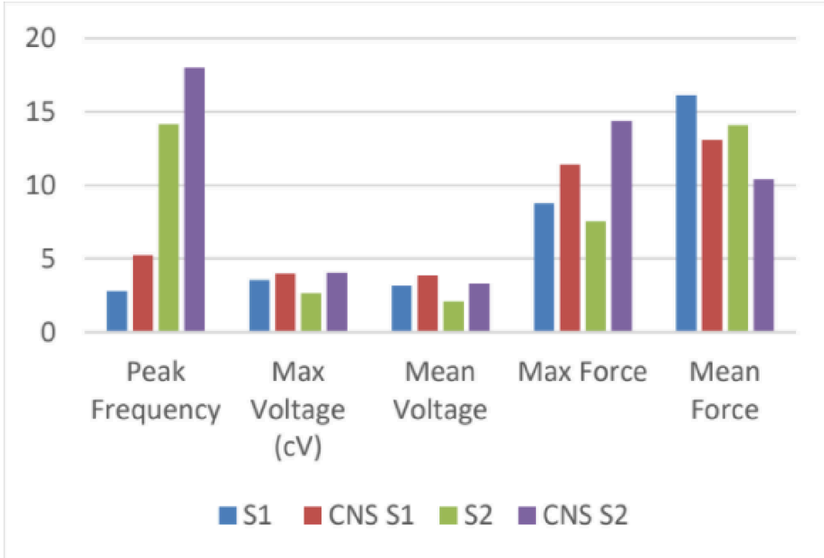

Figure 1: Graphs of Peak Frequency, Maximal Voltage, Mean Voltage, Maximal Force, & Mean Force for Electromyostimulation and Muscle Fatigue of Subjects I and II.

Reductions in each category due to electromyostimulation (S1 and S2) were plotted against the reductions in each category due to muscular fatigue. Relevant insights were obtained that indicated a proportional relationship between muscular fatigue and electromyostimulation. However, the result provided for mean force was inconclusive, and requires further exploration with a larger sample size.

G. Schedule

Upon approval of the investigation, time will be needed to recruit human volunteers for testing; one month will suffice for this recruitment phase. Two weeks will be needed four the experimentation team to conduct the experiments and another two weeks for data processing and reporting. Thus, the following schedule is proposed:

- March 01, 2022: Volunteer recruitment phase begins.
- April 03, 2022: Testing phase begins.
- April 18, 2022: Data processing phase begins.
- April 29, 2022: Reporting of results.

H. Costs

Materials and apparati will need to be obtained to continue investigation into the effectiveness of the electrical muscle stimulus in reducing muscular inflammation and fatigue. It is recommended that two sets be secured to ensure that technical difficulties do not impact the conduction of the tests and to permit the conduction of more trials simultaneously. Human test subjects will be needed, thus, advertising for volunteers will be necessary. The expenses are estimated in Table V.

Item or Commodity	Quantity	Cost (USD)
Electronic Muscle Stimulator Unit	1 (2)	100 (200)
Vernier Hand Dynamometer	1 (2)	200 (400)
Advertising		50
Total:		350 (650)

*Recommended values are in parentheses.

Table 5: The Estimated Expenses for Conduction of EMS Testing on Human Subjects.

As seen in Table V, the costs of the units needed for the investigation are less than the alternatives listed in Table I. It is hoped that this system will permit a low-cost alternative for patients and healthcare professionals to be utilized to treat skeletal muscle inflammation and fatigue.

I. Future Work

If successful, a therapy system utilizing electronic muscle stimulation will be able to be developed and with a lower cost compared to alternative means. This will enable the product to be marketed to organizations with smaller budgets that cannot afford the more expensive alternatives.

Approval is needed so the materials and apparati can be purchased and recruitment can begin. Upon completion of the testing phase, the data collected will need to be processed, then reported.

If the proposed system works as desired, an investigation will be needed to determine the marketability of the system, then prototypes will need to be produced.

J. Conclusion

The previous study discussed in the Details, Data Analysis, and Testing Results sections demonstrated that electromyostimulation can create fatigue by stimulating skeletal muscles. This can be used for therapeutic treatment of muscular injury, but there is uncertainty to what extent the technique can be used. Thus, additional research and testing needs to be conducted to determine if electromyostimulation therapy can be used to decrease skeletal muscle inflammation and fatigue and to what extent the methods can be therapeutic.

K. References

Dynamic Wellness. (2018). *Low Level Laser Therapy: How Much Does it Cost?* Dynamic Wellness & Chiropractic. Accessed from https://www.dynamicwellnesschiro.com/how-much-is-low-level-laser-therapy/.

Summary: This website discusses low level laser therapy, its use for treatment of injury, joint pain and muscle stress, and its clinical costs. The cost to the patient per visit for this therapy was stated at being between $60 to $250 USD.

The source was written for the general public by Dynamic Wellness, a Family & Sports Chiropractic Unit in Hyde Park, Tampa. The clinic is operated by Dr. Larry Wilson, a certified physician who had previously served as President of the Student American Chiropractic Association, and received a nomination for a Clinical Excellence Award.

Gondin, J., Cozzone, P. J., & Bendahan, D. (2011). *Is High-Frequency Neuromuscular Electrical Stimulation a Suitable Tool for Muscle Performance Improvement in Both Healthy Humans and Athletes?* European Journal of Applied Physiology, 111(10), 2473–2487. https://doi.org/10.1007/s00421-011-2101-2

Leal, E. C. P. Jr., Lopes-Martins, R. Á. B., Rossi, R. P., De Marchi, T., Baroni, B. M., de Godoi, V., Marcos, R. L., Ramos, L., Bjordal, J. M. (2009). *Effect of cluster multi-diode light emitting diode therapy (LEDT) on exercise-induced skeletal muscle fatigue and skeletal muscle recovery in humans.* Lasers in Surgery and Medicine, 41, 8, pp. 572-577. Accessed from https://doi.org/10.1002/Ism.20810.

Summary: This article reports the effects of using light emitting diode therapy on muscular performance, fatigue, and skeletal muscle recovery biochemical markers. The scholarly journal investigates claims that LED cluster probes are effective alternatives to low-level laser therapy.

Tests were performed on the biceps humeri of adult male professional volleyball players. Leah Jr. et al. concluded that LED therapy caused a slight delay in skeletal muscle fatigue and a decrease in post-exercise Lactate Enzyme, Creatine Kinase and C-Reactive Protein.

Mantineo, M. E., Pinheiro, J. P., Morgado, A. M. (2014). *Low-level laser therapy on skeletal muscle inflammation: evaluation of irradiation parameters.*Journal of Biomedical Optics, 19(9), 098002. Accessed from https://doi.org/10.1117/1.JBO19.9.098002.

Summary: This article reports on the findings of a study of the effectiveness of using low-level laser therapy in treating induced inflammation in a rat's gastrocnemius muscle. The inflammation was induced using cytokines concentrations in the rat's systemic blood, and was reduced most effectively with a 40mW laser with continuous irradiation.

Neric, F. B., Beam, W. C., Brown, L. E., & Wiersma, L. D. (2009). *Comparison of swim recovery and muscle stimulation on lactate removal after sprint swimming.* Journal of Strength and Conditioning Research, 23(9), 2560–2567. https://doi.org/10.1519/jsc.0b013e3181bc1b7a

Platinum LED Therapy Lights. (2021). *How Much Does Red Light Therapy Cost?* Platinum LED Therapy Lights. Accessed from https://platinumtherapylights.com/blogs/news/red-light-therapy-cost.

*Summary:*This article describes what red light therapy is, what it is used for, how it works, advice for at-home usage, and the clinical and at-home costs. The clinical cost to the patient was reported as being from $25-$200 USD. This article was written for the general public and is focussed on treating more superficial conditions.

Porcari, J., McLean, K., Foster, C., Kernozek, T., Crenshaw, B., & Swenson, C. (2002). *Effects of Electrical Muscle Stimulation on Body Composition, Muscle Strength, and Physical Appearance,* 16(2), 165. https://doi.org/10.1519/1533-4287(2002)016<0165:eoemso>2.0.co;2

Seo, B., Kim, D., Choi, D., Kwon, C., & Shin, H. (2011). *The effect of electrical stimulation on blood lactate after anaerobic muscle fatigue induced in taekwondo athletes.* Journal of Physical Therapy Science, 23(2), 271–275. https://doi.org/10.1589/jpts.23.271

Seyri, K. M., & Maffiuletti, N. A. (2011). *Effect of Electromyostimulation Training on Muscle Strength and Sports Performance.* Strength & Conditioning Journal, 33(1), 70–75. https://doi.org/10.1519/ssc.0b013e3182079f11

Wirtz, N. C. Z. (2016, March 1). Directory of Open Access Journals. Nicolas Wirtz, Christoph Zinner, Ulrike Doermann, Heinz Kleinoeder, Joachim Mester. https://doaj.org/article/5ca53c69851140b2acc97194d581bad4

Appendix: Contributions

Personnel	
Name	**Contribution**
Aly Khan Nuruddin [Arbiter]	Design Overview, Design Evaluation Methodology, Data Analysis, Testing Results
DongWoo Han [Final Editor]	Summary, Personnel, Introduction, References
Raymond Hubscher [Initial Editor]	Alternative Solutions, Schedule, Costs, Future Work, Conclusion