

Alteration of UE postural responses to low-frequency fatigue : a grant proposal

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FINAL APPROVAL OF SCHOLARLY PROJECT
Doctor of Physical Therapy Degree

**Alteration of UE Postural Responses to Low-Frequency Fatigue:
A Grant Proposal**

Submitted by

Allen M. Bresson

In partial fulfillment of the requirements for the degree of
Doctor of Physical Therapy

Date of Presentation:

June 28, 2006

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Alteration of UE Postural Responses to Low-Frequency Fatigue: A Grant Proposal

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December 1, 2006

Abstract

Study Design: Repeated Measures Design

Background: Active loading/unloading occurs when the subject loads/unloads the weight from their own forearm with their opposite UE. It has been shown, as in Figure 3, that with active unloading, there is an inhibition of the biceps brachii of the postural arm just prior to the unloading of the arm. It is therefore called an anticipatory response and this along with the precise coordination between the postural arm and the opposite UE helps prevent an upward forearm displacement. Passive loading/unloading occurs when someone other than the subject loads/unloads the weight from the subjects forearm. Inhibition of the postural arm's bicep brachii occurs just after the weight had been unloaded resulting in a loss of postural control and a consequently upward forearm displacement. Therefore, passive unloading is a triggered response. Peripheral fatigue is "fatigue produced by changes at or distal to the neuromuscular junction and is characterized by the inability to sustain a target level of force output due to failure at points along the excitation-contraction coupling mechanism with the weakest link being the sarcoplasmic reticulum. LFF is characterized by a disproportionate loss of force at low frequencies of stimulation compared to high frequencies when tested using electrical stimulation. Twitch torque ratio (TTR) compares the force production caused by high frequency stimulation to the force production caused by a low frequency stimulation of a muscle. An increase in the TTR when comparing the force output of a fresh muscle to the force output of a fatigued muscle indicates that the subject is in a state of LFF.

Methods and Measures: Pre-treatment phase consists of taking baseline measurements for MVCC and TTR and completing a set of 32 postural control trials consisting of 16 different conditions of loading and unloading the forearm. The fatigue group then undergoes a fatiguing exercise protocol while the control group rests. Measurements for MVCC and TTR and the completion of the postural control trials will be taken immediately, 15 minutes, 24 hours, and 96 hours after the treatment phase.

Results: It is expected that when the fatigued bicep is being used as the posture control muscle during active unloading, active loading, and passive unloading of the weighted peg, there will be a downward forearm displacement as compared to baseline. With passive unloading of the fatigued bicep as the posture control muscle, it is expected that there will be an increased upward forearm displacement as compared to baseline. When the fatigued bicep is being used as the load control muscle, it is expected that there will be no change in the forearm displacement of the opposite, non-fatigued UE as compared to baseline for active loading, active unloading, passive loading, and passive unloading.

Conclusion: Patients of physical therapy may be at a significant risk of the effects of LFF due to the physical demands that are placed on them. Patients with neurological disorders may already have decreased or increased reflex responses depending on their impairments, which affect their ability to control their posture. As they are exercised and become fatigued, they may be at a higher risk for the next few days for further injury during a submaximal activity outside of the clinic. Possibly being able to detect LFF and its affect on postural control may enable patients to be educated on injury prevention techniques to decrease risk of an injury.

Table of Contents

I. Resources	2
II. Background	
A. Reflex Response	3
B. UE Posture	5
C. Fatigue	7
III. Specific Aims and Hypotheses	9
IV. Research Design and Methods	
A. Subjects and Controls	10
B. Familiarization	11
C. Pre-Treatment Phase	11
D. Treatment Phase	12
E. Post-Treatment Phase	13
F. Data Analysis	15
V. Rationale and Significance	16
VI. Citations	18
VII. Appendix	20

I. Resources

Laboratory:

Messaros laboratory, 0203 Collier Building, UT Health Science Campus: over 440 sq. ft. of dedicated private space available anytime for the proposed study; easily accessible to subjects driving from off-campus; all data in the basic science core and the applied science core of this proposal will be collected and analyzed in this space; includes sink, work tables, phone, shelving, meeting table, whiteboard, and mobile amplifier racks.

Clinical:

Allied Health Clinic, 0212 Collier Building, UT Health Science Campus: approximately 900 sq. ft. of private space complete with clinic tables, mats, sink, and equipment used by physical therapists; the room is located across the hallway from the Messaros laboratory and is easily accessible to subjects arriving from off-campus.

Animal:

n/a

Computer:

Messaros laboratory: dual-processor, dual monitor Mac G5 OS x 10.4, 1GB RAM; single-processor Windows XP (Nov. 2004); 12 ppm duplex scanner; 6MB HP laser-jet printer.

Messaros office: Mac and Windows computers, identical to aforementioned

Office:

Messaros office: 4208 Collier Building; located directly above laboratory space

Messaros laboratory: desk, chair, shelving, and space already exist

Other:

Dr. Goel: the laboratories of mechanical/electric shops of the College of Engineering (UT Main Campus) and Dept. of Orthopedics (UT HSC) to design/develop experimental fixtures

Major Equipment:

The following are already located in the Messaros laboratory:

- 8 channel surface/indwelling electromyography amplifiers (research-grade)
- 2 channel footswitch input
- 4 channel Tektronix digital oscilloscope
- Computer-controlled Digitimer electric muscle stimulator (400V, 1A)
- Variety of accelerometers, tension/compression load-cells, and joint angle position transducers
- Biopac transducer amplifiers and multiplexed data acquisition/analysis software for transducers
- Biopac computer-controlled output devices including sound generator, waveform generator, stroboscope.

II. Background

A. Reflex Response

A reflex is a stereotypic motor response elicited by a given sensory stimulus. For example, a tap of the patellar tendon (sensory stimulus) elicits a knee extension response (motor response). Reflexes, though, are much more complex than this simple sensory stimulus and motor response. The sensory stimulus will stretch the muscle and its muscle spindles causing excitation of Ia afferent fibers that travel to the spinal cord through the dorsal root and synapses on an alpha motor neuron. The spinal cord takes the available information and sends an inhibitory signal down to the antagonist muscle and an excitatory signal to the agonist muscle to cause the quick muscle contraction.

The human reflex response is a great feature in that the signals eliciting the reflex do not have to be sent to the central nervous system (CNS) to be processed. Reflex circuitry assists the CNS by reducing the degrees of freedom available during a motor task. In other words, supraspinal processing is not required to make a decision regarding each movement we make. Reflexes, therefore, become the building blocks for movement. For example, the asymmetrical tonic neck reflex (ATNR), found in infants less than 3 months old, is displayed when the head is rotated to one side. With this rotation, the ipsilateral upper extremity (UE) extends while the contralateral UE flexes. It was once thought that reflexes, such as the ATNR, just disappeared with age and they were never used again. It is now known that these reflexes are integrated into our everyday movements and becomes obligatory in that we are able to choose when or not to use them². A lay-up in basketball is just one example of our obligatory use of the ATNR reflex later in life as we extend one UE and flex the other as our head is rotating.

Each reflex response depends on the initial conditions whether these conditions are internal, external, central, or peripheral. One of the most important conditions affecting the reflex response is the twitch properties of muscle. Twitch properties include a latent period, period of contraction, and period of relaxation. Figure 1 illustrates a single twitch and its properties.

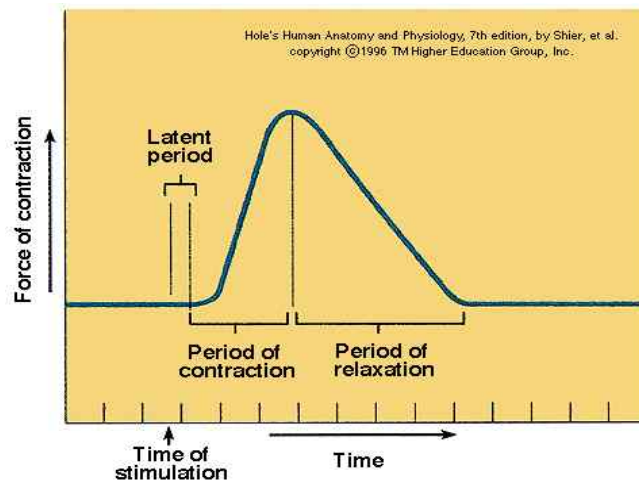


Figure 1

The latent period begins when the decision of contraction is made until the contraction actually begins, which includes the firing of motor neurons in the brain and down the spinal cord, the action potential reaching the sarcoplasmic reticulum (SR), and calcium being released. During the period of contraction, calcium is bound to troponin and the actin and myosin are sliding across one another. Finally, during the period of relaxation, calcium is released from troponin and at the half relaxation time, the calcium begins to be taken back up by the SR. This will be explained further in the fatigue discussion. These twitch properties are so important because they directly determine the tetanizing fusion frequency, or how many times the muscle must be stimulated in a given amount of time in order to reach and sustain a tetanus contraction. If this fusion frequency is

changed, the initial condition is altered and therefore the reflex response may no longer be stereotypical. Twitch properties will be discussed further later in the discussion.

B. UE Posture

Posture is defined as the position of a given body segment in space. Postural control is the regulation and/or maintenance of a joint angle and is largely a reflex response that helps the human body maintain their balance⁸.

In this study, the postural control of the elbow joint will be the focus. This will be done through a process of weighting and unweighting the forearm with the goal always being to maintain the same joint angle. The forearm will be loaded/unloaded actively and passively.

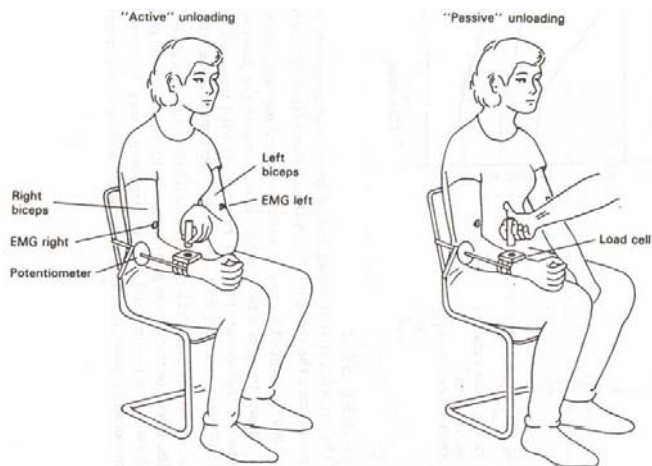
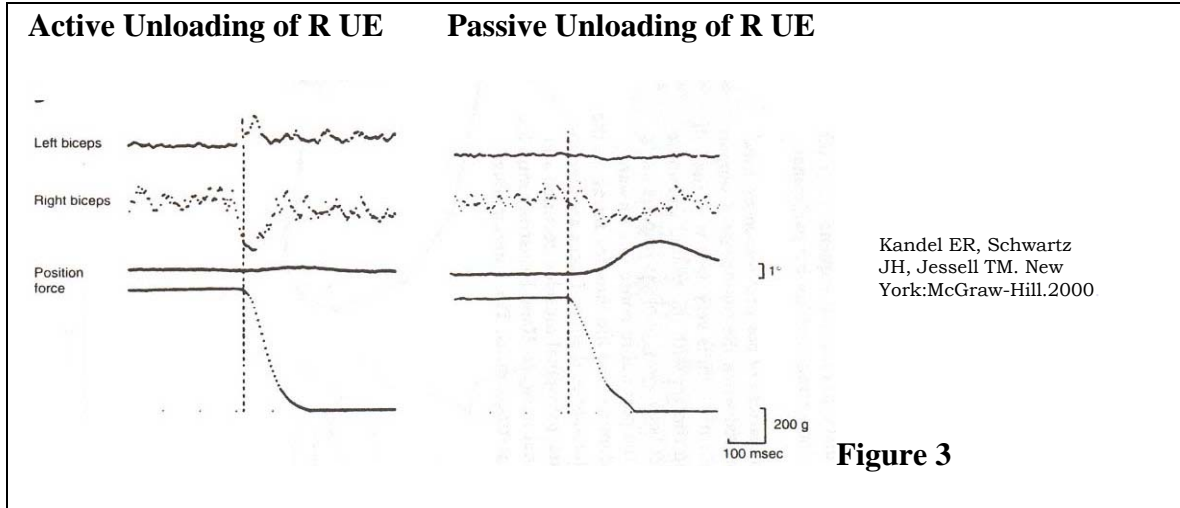


Figure 2

As shown in Figure 2, active loading/unloading occurs when the subject loads/unloads the weight from their own forearm with their opposite UE. It has been shown, as in Figure 3, that with active unloading, there is an inhibition of the biceps brachii of the postural arm just prior to the unloading of the arm. It is therefore called an anticipatory response and this along with the precise coordination between the postural arm and the opposite UE helps prevent an upward forearm displacement^{3, 8, 12}.



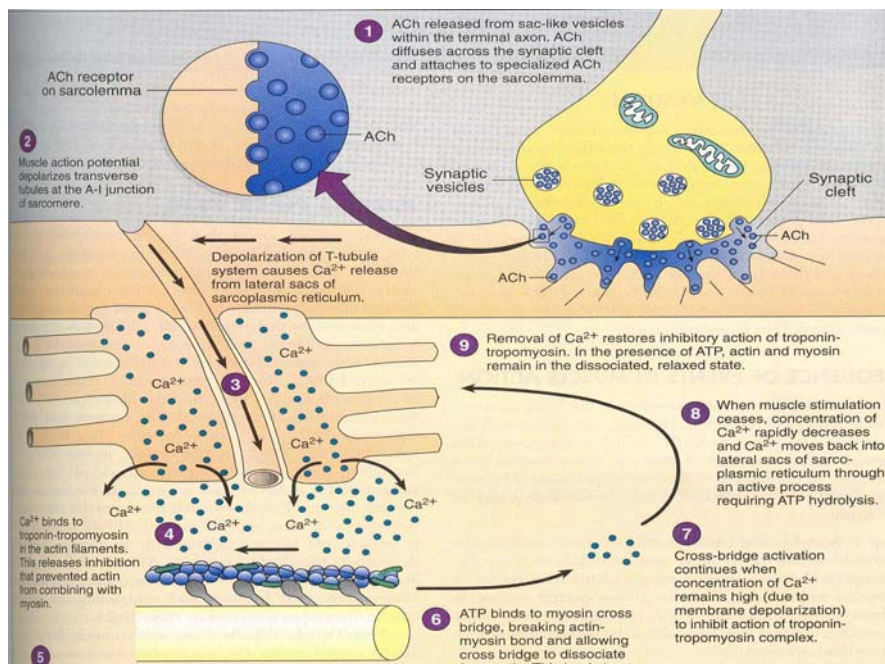
Passive loading/unloading occurs when someone other than the subject loads/unloads the weight from the subjects forearm. Figure 3 also shows that with passive unloading, the inhibition of the postural arm's bicep brachii occurs just after the weight had been unloaded resulting in a loss of postural control and a consequently upward forearm displacement. Therefore, with passive unloading, it is a triggered response instead of an anticipatory response^{3, 8, 12}.

It is important to understand that anticipatory and triggered responses are not mutually exclusive. They operate on a continuum, so for each reflex response, central and peripheral mechanisms will use a combination of both anticipatory and triggered responses. Where on the continuum the response acts on is dependent on the initial conditions and the stimulus that elicits the response, as discussed before. Anticipatory and triggered responses must be balanced along the continuum in order for proper postural control and they are controlled by both peripheral and central mechanisms^{3,5,15}.

C. Fatigue

Muscle fatigue is a temporary loss in force or the inability to generate a required torque or power output. Fatigue is induced by exercise or a recent muscle contraction and is relieved by rest. There are two types of fatigue, central and peripheral. Central fatigue is caused by impairments from the brain down to the alpha motor neuron. It has a long duration and is usually associated with cognitive activities and motivation^{6,9}.

Peripheral fatigue, which will be the focus of this study, is “fatigue produced by changes at or distal to the neuromuscular junction”⁶. It is characterized by the inability to sustain a target level of force output due to failure at points along the excitation-contraction (EC) coupling mechanism⁶. Figure 4 illustrates this complicated process. EC coupling begins when the acetylcholine (ACh) neurotransmitter is released at the



McArdle WD, Katch FI, Katch VL. Baltimore, MD: Williams&Wilkins. 1996.

Figure 4

neuromuscular junctions. ACh then travels across the synapse and attaches to receptors on the sarcolemma. This causes an action potential that depolarizes down the T-tubule and into the sarcoplasmic reticulum (SR). Ca^{++} is released and is binds to the troponin-

tropomyosin complex allowing the cross bridge formation and muscle fiber contraction. When muscle stimulation is finished, Ca^{++} unattaches to troponin and is rapidly taken back up by the SR.

The weakest link in the EC coupling process that leads to peripheral fatigue is an impairment of the SR. There are three proposed mechanisms for peripheral fatigue: (1) a decrease in the Ca^{++} sensitivity by troponin (2) reduced Ca^{++} reuptake by the SR after the muscle contraction (3) and the primary mechanism being a decreased Ca^{++} release from the SR. Each of these mechanisms reduce the total amount of Ca^{++} available to bind to troponin and hinders the ability of the muscle to contract^{4,10}.

There are two types of peripheral fatigue, high frequency fatigue (HFF) and low frequency fatigue (LFF). LFF is believed to be more prevalent and will therefore be the focus for this study.

LFF is characterized by a disproportionate loss of force at low frequencies of stimulation compared to high frequencies when tested using electrical stimulation. To detect LFF, the twitch torque ratio (TTR) is calculated. This compares the force production caused by high frequency stimulation to the force production caused by a low frequency stimulation of a muscle. An increase in the TTR when comparing the force output of a fresh muscle to the force output of a fatigued muscle indicates that the subject is in a state of LFF. Once in a state of LFF, the maximal force production will not be restored for a time in excess of 3 days after the fatiguing exercise^{1,14}. LFF is not caused by activities that require only low frequencies of muscle activation or low frequencies of electrical stimulation¹⁴. It has been found to occur after periods of high intensity

contractions like that done during weight training. It has also been found to occur following repetitive maximal electrical stimulation¹³.

The twitch properties of muscle are altered when a subject is in a state of LFF. Most notably, LFF will cause a decreased peak torque output, decreased time to reach the peak torque, and an increased relaxation time⁷. When the relaxation time is increased and the peak torque is decreased, the fusion frequency to reach a tetanus contraction is reduced, as shown in Figure 5. The alteration LFF has on twitch properties changes the initial conditions set before an anticipatory or triggered response and therefore alters these responses.

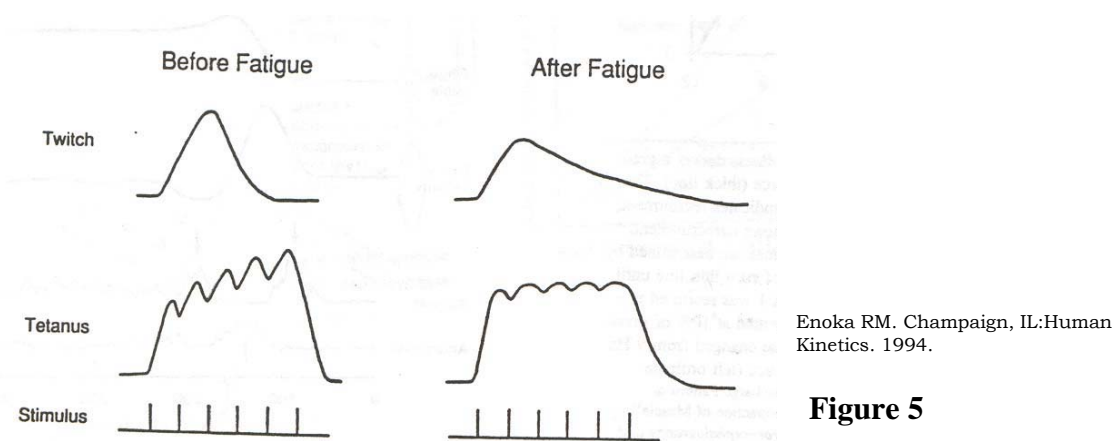


Figure 5

III. Specific Aims and Hypotheses

There are several aims for this proposed study. The first is to examine the effects of LFF on postural control as measured by the magnitude of forearm displacement during a loading and unloading task. The study will also examine the relationship between LFF and the timing and amplitude of EMG activity in the biceps brachii of the postural UE during a loading and unloading task. The study will look for a relationship between loading and unloading a weight using a fatigued UE and loading and unloading a weight

using a non-fatigued UE. Finally, the study will look for a relationship between active and passive unloading compared to active and passive loading while in a state of LFF.

With the given background, the researcher's hypothesis is that the presence of LFF will lead to alterations in both anticipatory and triggered responses as indicated by a loss of postural control in the fatigued UE during loading and unloading and while under active and passive conditions. The null hypothesis, on the other hand, states that LFF will have no impact on anticipatory or triggered responses and therefore no impact on postural control during unloading and loading of the fatigued UE and while under active and passive conditions.

It is expected that when the fatigued bicep is being used as the posture control muscle during active unloading, active loading, and passive unloading of the weighted peg, there will be a downward forearm displacement as compared to baseline. With passive unloading of the fatigued bicep as the posture control muscle, it is expected that there will be an increased upward forearm displacement as compared to baseline.

When the fatigued bicep is being used as the load control muscle, it is expected that there will be no change in the forearm displacement of the opposite, non-fatigued UE as compared to baseline for active loading, active unloading, passive loading, and passive unloading.

IV. Research Design and Methods

A. Subjects and Groups

The subjects for this study will be composed of right-hand dominant males and females between the ages of 21 and 40. The subjects need to be able to tolerate

supramaximal biceps brachii electrical stimulation. They will also need to be able to elicit two consecutive maximal voluntary concentric contractions (MVCC) that are within 10% of the preceding contraction. The subjects will be excluded if they have initiated a new weight-training program involving the upper extremities during the prior six weeks. Exclusion will also apply to subjects who have a history of any upper extremity musculoskeletal or neurological disorders. Once subjects are included in the study, they will be randomly chosen for one of two groups; a fatigue group and a control group. The fatigue group will undergo an exercise fatigue protocol consisting of repetitive concentric elbow flexion exercises while the control group rests quietly for 15 minutes.

B. Familiarization Day

The first day the subjects report to the lab will be a familiarization day. All necessary paperwork will be completed and the methods and protocols will be reviewed. This will also give the subjects a chance to feel the electrical stimulation to see if they will be able to tolerate the supramaximal stimulation that they would endure. The subjects would be able to practice using an oscilloscope for feedback during concentric contractions. Finally, the investigators will take initial positioning measurements for each patient for an isokinetic dynamometer and the postural control station.

C. Pre-Treatment Phase

On the day the study begins, the subjects will report to the lab and all baseline measurements will be taken during the pre-treatment phase. The twitch torque ratio will be determined by measuring the torque output from the biceps brachii muscle in the left UE during 15 Hz of electrical stimulation (low frequency) and 100 Hz of electrical

stimulation (high frequency). This frequency ratio of 15:100 Hz has been found to be the most sensitive at detecting LFF¹¹. Next, electrodes will be placed and an EMG will be taken of the bilateral bicep brachii muscles while at rest and during the testing of the subject's baseline MVCC for each UE. A potentiometer will then be placed on each UE at the elbow joint to make sure it is in the proper position to read the accurate joint angle. Finally, with the EMG machine on, the subject will be placed at the postural control testing station and taken through each of the 32 trials that will be explained later to get baseline readings.

D. Treatment Phase

After the pre-treatment phase is over, the treatment phase will begin. During this time, the control group will rest for 15 minutes and the fatigue group will undergo its exercise fatigue protocol. During this fatiguing protocol, the subjects in the fatigue group will be set up in an isokinetic dynamometer. Their left shoulder will be placed in 90 degrees of abduction and 30 degrees of horizontal adduction. Finally, the subjects' forearm will be placed in supination and their wrist will remain neutral. The placement of the UE in the isokinetic dynamometer is necessary to isolate the bicep brachii. Once the subject is set up, they will be instructed to flex the elbow in a range previously set from 30 degrees to 120 degrees at a speed of approximately 30 degrees per second. Their goal will be to concentrically contract their biceps producing at least 75 percent of their MVCC for as many times as possible and to not stop until told so. An oscilloscope will be placed in front of them displaying their speed of elbow flexion and the percent of MVCC they are contracting at to provide feedback of their performance. The exercise

will come to a stop when the subjects reach a standardized criterion that they are blinded to in order to get their best effort. This stopping criterion will be defined as the inability to reach their 75% MVCC during three consecutive concentric contractions. Once the stopping criterion has been met, the subject will stop exercising and be locked into 90 degrees of elbow flexion. The TTR will be calculated by stimulating them again at 15 Hz and 100 Hz to identify whether or not they are in a state of LFF. If they are not in a state of LFF, they will restart the exercise protocol until they are found to be. When LFF is reached, the exercise will stop and the post-treatment phases will begin.

E. Post-Treatment Phase

After the treatment phase, they will immediately be taken to the postural control testing station. Here the subjects from both groups will be seated and blindfolded with their left shoulder in neutral, elbow in 90 degrees of flexion, forearm in supination, and their wrist neutral, as shown in Figure 6. They will then proceed to complete a series of

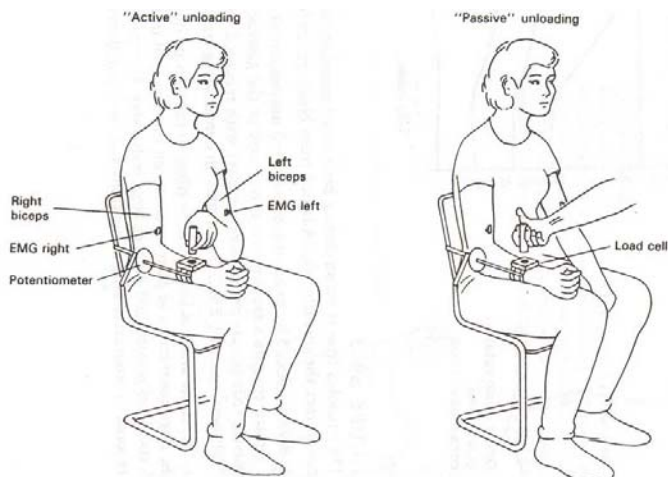


Figure 6

loading and unloading activities that include 16 different conditions and each condition will be completed two times making a total of 32 trials. The main goal for each trial will

be to maintain their elbow joint angle as a weighted peg is unloaded off of or loaded onto their forearm under different conditions. (each specific condition is contained in Appendix 1)

When the peg is being unloaded from the subject's forearm, it will be under active and passive conditions. During active unloading, the subject will remove the peg using the wrist of the opposite UE to which a hook has been attached. As the peg is hooked and being removed, the goal will be to concentrically contract the load control biceps while eccentrically contracting the postural UE so the elbow joint is not displaced. Under passive unloading, as the investigator removes the peg from the postural UE, again the goal will be to maintain their elbow joint angle.

When the peg is being loaded onto the postural forearm, it will be under the same active and passive conditions. During active loading, the subject will replace the peg onto the wrist using the opposite UE to which the hook is attached. The load control biceps will need to eccentrically activate and the postural bicep will need to concentrically activate in order to maintain the elbow joint angle. Under passive unloading, the investigator will place the weighted peg onto the postural UE at the forearm.

Each UE will take turns acting as the postural control and as the opposite load control. This will allow the investigator to determine whether or not the role of the UE and whether it's fatigued or not has an effect on the elbow displacement of the postural control UE. Finally, the last condition that will be manipulated is the weight of the peg. Two weighted pegs will be used; 0.5 kg and 2.0 kg. This will allow the investigators to

identify the effect of weight on the ability to control the posture of the elbow joint during loading and unloading activities and in fatigued and non-fatigued states.

Fifteen minutes after the treatment phase, the postural control trials will be repeated and the MVCC and TTR measures will be taken. After 24 hours of recovery, the subjects will return to the lab to take the MVCC and TTR measures and then repeat the postural control trials. Finally, 96 hours after the treatment phase, the subjects will return for the last time to measure MVCC and TTR and complete the postural control trials. (See Appendix 2 for summary of the subject schedule) By taking these measurements after different times during their recovery, the investigators are able to see what phase of recovery from LFF they are in and how this relates to their MVCC and ability to maintain postural control during the different trials.

F. Data Analysis

After all data has been collected over the various phases of the study, a descriptive statistical analysis will be completed in an attempt to demonstrate the presence or absence of a phenomenon and not necessarily to quantify the statistical frequency with which this phenomenon occurs. In this study there is one main independent variable that the investigator manipulates and that is the 25 percent decrease MVCC stopping criterion for the fatigue group. The dependent variables, therefore, would include the many measurements taken throughout the study. As it relates to the elbow joint angle stability, the dependent variables will be the following: maximal joint angle deviation, time of maximal joint angle deviation from point of loading and unloading, total area under joint angle deviation, and the time needed for the joint to

become stable again. As it relates to the postural control bicep EMG and the load control bicep EMG, the dependent variables will be the following: EMG peak amplitude, time of peak EMG amplitude from point of loading and unloading, total area under EMG, and time needed for the EMG to get back to resting state.

A limitation of this study is that there is no pilot data on the effect of LFF on UE postural control and therefore, is not possible to determine the possible significant variables to focus on, hence the large amount of trials and data that must initially be taken.

V. Rationale and Significance

As I have previously explained, reflex responses such as that for postural control are dependent on the initial condition, most notably the twitch properties of muscle. With LFF, it has been found that the twitch properties are altered in various ways, such as increased relaxation time. Therefore, when LFF is present and twitch properties are altered, the initial conditions are different which likely leads to a change of anticipatory and triggered responses for the worse.

The information that could possibly be obtained from this study could potentially be used in prevention of injury while in a state of LFF and during submaximal bimanual tasks. Since LFF is long lasting, silent, and affects submaximal activities, this makes LFF that more dangerous during our daily activities.

Patients of physical therapy may be at a significant risk of the effects of LFF due to the physical demands that are placed on them. Patients with neurological disorders may already have decreased or increased reflex responses depending on their

impairments, which affect their ability to control their posture. As they are exercised and become fatigued, they may be at a higher risk for the next few days for further injury during a submaximal activity outside of the clinic. Possibly being able to detect LFF and its affect on postural control may enable patients to be educated on injury prevention techniques to decrease risk of an injury.

There has been a large amount of research on LFF and also an extensive amount of research on postural control, but there is no research that specifically looks at the effect of LFF on postural control like this study does, which is why this study could be so important. This may open the doors to future studies on the effects of LFF on the lower extremity (LE) postural control during balance activities or ambulation. What is learned through this study about UE postural control may correlate with the control of the spine and eventually be applied to the large amount of low back pain patients in this country.

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VII. Appendix

Appendix 1: Posture Control Trials

	Peg Action	Condition	Role of L UE	Peg Weight
1	Load	Active	Postural	0.5 kg
2	Load	Active	Postural	2.0 kg
3	Load	Active	Load Control	0.5 kg
4	Load	Active	Load Control	2.0 kg
5	Load	Passive	Postural	0.5 kg
6	Load	Passive	Postural	2.0 kg
7	Load	Passive	Load Control	0.5 kg
8	Load	Passive	Load Control	2.0 kg
9	Unload	Active	Postural	0.5 kg
10	Unload	Active	Postural	2.0 kg
11	Unload	Active	Load Control	0.5 kg
12	Unload	Active	Load Control	2.0 kg
13	Unload	Passive	Postural	0.5 kg
14	Unload	Passive	Postural	2.0 kg
15	Unload	Passive	Load Control	0.5 kg
16	Unload	Passive	Load Control	2.0 kg

** 2 trials per combination above totaling 32 trials each phase

Appendix 2 : Subject Schedule

<p>Orientation Session</p> <ul style="list-style-type: none"> - Complete paperwork, review study protocol, test subject tolerance to electric stimulation, subject practice using oscilloscope feedback, positioning measurements
<p>Day 1</p> <ul style="list-style-type: none"> - Pre-Treatment Phase: Measure MVCC, TTR, and complete postural control trials while fresh - Treatment Phase: Exercise for fatigue group; rest for control group. - Post-treatment Phase: Immediately measure MVCC, TTR, and complete postural control trials. - Post-treatment Phase: After 15 minutes of rest, measure MVCC, TTR, and complete posture control trials.
<p>Day 2</p> <ul style="list-style-type: none"> - Twenty-four hours following treatment phase, measure MVCC, TTR, and complete posture control trials.
<p>Day 3</p> <ul style="list-style-type: none"> - Ninety-six hours following the treatment phase, measure MVCC, TTR, and complete posture control trials.