1-1-2016

Effects Of Local Muscle Fatigue On Proprioception And Motor Learning

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EFFECTS OF LOCAL MUSCLE FATIGUE ON PROPRIOCEPTION AND MOTOR LEARNING

by

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THESIS

Submitted to the Graduate School

of Wayne State University,

Detroit, Michigan

in partial fulfillment of the requirements

for the degree of

MASTER OF EDUCATION

2016

MAJOR: KINESIOLOGY & EXERCISE SCIENCE

Approved By:

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Advisor Date

ACKNOWLEDGEMENTS

The Kinesiology and Exercise science department faculty have been very kind to me. First and foremost I would like to thank Dr. Qin Lai, Associate Professor and thesis advisor, for giving me the opportunity to work, learn and study under him. This research would not be possible without his guidance and assistance. No one would get much work completed without the help and support of administrative assistants; I would like to extend a special thank you to Ms. Carol Salisbury.

I would also like to express my appreciation for Dr. Hermann- Josef Engles, Professor and Academic Advisor, for his kind words and on-going encouragement and support. A thank you goes out to all the participants that volunteered their time to contribute to this study. Jena Rubino, undergraduate student and Dr.Wenjing Zhang, visiting scholar for their assistance in the data collection process.

A special thank you goes out to my parents who have loved me, supported me always.

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CHAPTER 1

INTRODUCTION

Proprioception, or kinesthesia, is the sense that lets us perceive the location, movement, and action of parts of the body. It encompasses a complex of sensations, including perception of joint position and movement, muscle force, and effort. These sensations arise from signals of sensory receptors in the muscle, skin, and joints, and from central signals related to motor output. Proprioception enables us to judge limb movements and positions, force, heaviness, stiffness, and viscosity. It combines with other senses to locate external objects relative to the body and contributes to body image. Proprioception is closely tied to the control of movement. The joint position sense is a very important contributor to joint coordination, maintenance of muscle stiffness, and the production of natural movements for appropriate task performance. Joint position sense minimizes the risk of joint injury.

Muscle fatigue is an exercise induced decline in the ability of muscles to produce force or power. Muscle fatigue can also alter proprioception. Previous studies have demonstrated the effects of muscle fatigue on proprioception (e.g., Carpenter, Blasier, &Pellizzon, 1998). Carpenter et al. investigated how local muscle fatigue affected shoulder proprioception. Their study included 20 volunteers without any shoulder abnormalities. The shoulder proprioception was assessed by measuring the threshold of initial detection of shoulder rotation with the joint in 90 degrees of abduction and 90 degrees of external rotation. The results showed that the threshold for movement detection was increased by 1.59 degrees after a fatigue protocol. Carpenter et al. indicated this threshold increase was related to a degraded accuracy on the shoulder proprioception. Another study was done on shoulder to evaluate the glenohumeral proprioception following muscle fatigue (Lee, Liau, Cheng, Tan, & Shih, 2003). Lee et al.'sstudy revealed that local muscle fatigue degraded the shoulder proprioception mainly in active repositioning when the shoulder was in external rotation. The study also revealed that the shoulder proprioceptive ability was increased for the participants with increased resistance to muscle fatigue. Further, Chang, Chen, Wei, & Huang (2006) conducted an experiment on recovery of joint positioning sense in the shoulder after muscle fatigue. They found that proprioceptive recovery took longer time than strength following fatigue of the shoulder rotators. More recently, Vafadar, Cote, &Archambault (2012) studied the effects of muscle fatigue on position accuracy in an upper limb multi-joint task. Their results further supported that the position sense of the upper extremity could be degraded in the presence of fatigue.

On the other hand, some research on the lower extremity found the similar effects of muscle fatigue on proprioception. Arvin et al. (2015) investigated whether fatigue on the hip abductors affected gait control and hip position sense in healthy old adults. Their results showed negative effects on gait and hip position sense after a fatigue protocol on the hip abductors. Another experiment was to find out any changes on the position sense of the knee after exercise induced fatigue (Marks, 1994). Mark (1994) concluded that due to exercise induced contractile fatigue there was bias in encoding the positional information in the healthy knee. On a study investigating the effects of different levels of localized muscle fatigue on the knee position sense, Gear (2011) found that even mild and moderate fatigue had a negative effect on the proprioception. A recent study conducted by Han & Lee (2014) found the repositioning errors increased after the quadriceps muscle fatigue. Han & Lee also showed using kinesiology taping on the knee could decrease the repositioning errors. An experiment that compared the effects of active fatiguing movement and passive repetitive movement on the knee proprioception showed the absolute repositioning error was higher with repetitive active movements relative to repetitive passive movements (Ju, Wang, & Cheng, 2010).

Although most of previous studies on muscle fatigue detected a negative effect on limb positioning accuracy or proprioception, some research especially using foot positing task failed to reveal the fatigue effect. For example, South & George (2007) did not find any significant changes or errors in the ankle joint positioning at three target angles (90 degree inversion, 20 degree, inversion and 90 degree eversion) upon fatiguing exercise of the peroneal muscles. The no fatigue effect on the foot positioning might be related to relatively small range of motion and better reference on the ankle.

In an attempt to explain the changes of the neuromuscular recruitments affected by fatigue, Gonzalez-Izal et al. (2010) showed that the mean average voltage (MAV) and Dimitrov spectral index of the Electromyography (EMG) were recorded higher in the last five repetitions of each set and the first five of the fifth set when local dynamic fatiguing muscle was employed compared to the first five contractions without fatigue. They also found the muscle power obtained in the last sets was 45% lower than the first two repetitions of first set.

In summary, the published research literature generally found that local muscle fatigue decreased limb positioning accuracy for the upper and lower extremity (except the ankle) by degrading proprioception. However, these previous studies doesn’t investigate how degraded proprioception caused by muscle fatigue affects motor learning, in which a new skill is obtained during acquisition, retention, and transfer. Only one exception was a study done in 1974 by Cotten, Spieth, Thomas, &Biasiotto. They found fatigue had negative effect on performance but not learning.

PURPOSE OF THE STUDY

The primary aim of the study was to investigate the effects of local muscle fatigue on proprioception and motor learning. Specifically, the present study was to determine:

1. Whether the local muscle fatigue negatively affected the position learning accuracy.

2. Whether the fatigue effect was temporary (acquisition phase) or relatively permanent (retention phase).

3. Whether local muscle fatigue affected bilateral transfer or not (transfer phase).

4. How local muscle fatigue affected the changes of the neuromuscular recruitments indexed by the surface EMG.

HYPOTHESES

Based on the previous findings and the purpose of the study, the following hypotheses were proposed.

H1: Participants with a local muscle fatigue protocol decreased the accuracy when the forearm was flexed to specific angles relative to their controlled counterparts.

H2: Local muscle fatigue affected both acquisition performance and retention learning. Proprioception components of the motor learning.

H3: Bilateral transfer was affected by muscle fatigue but no difference between retention and transfer.

H4: Increased amplitude and decreased frequency of the EMG signals were detected when muscle was experienced fatigue.

DEFINITION OF TERMS

Fatigue: Muscle fatigue, or physical fatigue, is the decline in ability of a muscle to generate force.

Proprioception: The ability to sense stimuli arising within the body regarding position, motion, and equilibrium

Motor Learning: A set of internal processes associated with practice or experience leading to relatively permanent changes in the capability for motor skill.

Bilateral transfer: The ability to learn motor skill that one had previously mastered with one limb (usually the dominant hand) with the limb on the opposite side of t body (typically, the non-dominant hand).

Elbow flexion: A bending movement around elbow joint that decreases the angle between the bones of the limb at the joint.

Supination: Rotation of the forearm and hand so that the palm faces forward or upward.

EMG: Electromyography (EMG) is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons). Motor neurons transmit electrical signals that cause muscles to contract.

Kinesthesiometer: An apparatus for testing Kinesthesia or joint position sense.

ASSUMPTIONS

Participants did not have prior knowledge or practice of any experiment task. Participants would give their maximum effort during all the stages of the experiment (pre-test, acquisition and the retention tests).

DELIMITATIONS

Participants were male and female, ages 20-40, and enrolled in Wayne State University. All the participants used their left hand for most of the experiment except during transfer test where they used right hand.

LIMITATIONS

This study was limited to the amount of feedback given, to the place of Motor Behavior Lab, and also to the students from Wayne State University. The findings might not be generated for other manipulations in motor learning, different environment, and general population. The knowledge about participant's pre status of physical activity was also limited.

SIGNIFICANCE OF THE STUDY

The present study was an innovative attempt combining physiological variable (muscle fatigue) with motor learning procedure. The findings would enhance our knowledge how motor skill acquisition, retention, and transfer were affected by local muscle fatigue. This study would be also helpful in the clinical settings such as rehabilitation and sport training, while training the patient for the functional activities or athletes in the sports events. This knowledge has potential to assist the trainers or therapists in assessing the outcomes of training in a better ways and in planning the training protocol. Finally, local muscle fatigue and its effects on proprioception and motor learning is an important factor that should be taken into consideration during athletic training and treatment of other musculoskeletal injuries.

CHAPTER II

LITERATURE REVIEW

Fatigue and Proprioception:

In 2015, Abd-Elfattah, Abdelazeim, andElshennawy in a review article “physical and cognitive consequences of fatigue” termed fatigue as a decrease in physical performance associated with an increase in the real/perceived difficulty of a task or exercise. In another aspect, fatigue is defined as the inability of a muscle to maintain the required level of strength during exercise. Otherwise, it can be defined as an exercise induced reduction in muscle’s capability to generate force and the term is used to denote transient decrease in muscle capacity to perform physical activity. In the same study they also discussed various principles to distinguish the occurrence of muscle fatigue in response to physical activity. Those principles stated that there is no distinct mechanism to cause fatigue, but it is an intricate mechanism that includes central nervous system abnormalities and peripheral nervous system dysfunction. The origin of fatigue can be central, peripheral or both. Central fatigue is defined as a decrease in voluntary activation of a muscle, a reduction in discharge rate and number of motor units recruited at the beginning of muscle force generation (Abd-Elfattah, et al.), in other study by Vafader, Cote, and Archamabault (2012) stated central fatigue includes neurological mechanisms of change in subjective efforts, motivation, mood and pain tolerance as well as the mechanism that inhibit motor drive in upper regions of brain. Peripheral fatigue is described as a reduction in the contractile strength of a muscle fibers and changes in the process underlying the transmission of muscle action potential. These processes take place at the nerve endings and neuromuscular junction and are co-related with peripheral fatigue (Abd-Elfattah, et al., 2015). In other words, peripheral muscle fatigue is the inability of the muscle fibers to sustain a given intensity (Brooks et al., 2000; Vafadar, Cote, &Archambault, 2012).

Proprioception in the study by Vafader, Cote, and Archamabault (2012) is defined as the afferent information arising from mechanoreceptors located in the muscles, tendons, ligaments and skin around the joint. Among all, muscle spindles found in the skeletal muscle are considered as important proprioceptive receptors. The gamma motor system controls the sensitivity of the muscle spindle and also the output of muscle spindle is changed by increase in concentration of the intramuscular contractile substances. Therefore when the gamma motor neuron excitability is reduced then the muscle spindle sensitivity is also reduced thereby effecting proprioception. Muscle fatigue has been proposed as one of the factors that may be related with proprioception deficits, joint instability and injury. A study by Proske and Gandevia (2012) observed that muscle fatigue had increased the discharge rate of muscle spindles that lead to the changes in the limb positioning sense.

Effects of General or Central Fatigue on Proprioception:

Roijezon, Clark, Treleavan in a research article “Proprioception in musculoskeletal rehabilitation. Part 1: Basic science and principles of assessment and clinical interventions” stated that muscle fatigue includes various peripheral and central changes like altered muscle activation patterns, metabolic state, spinal reflexes and muscle spindle discharges and increased sense of effort. A common occurrence after performing hard exercise and physical activity is difficulty in carrying out fine motor tasks and exhibiting impaired proprioception (Röijezon, et al., 2015). In another research article by Gear (2011) mentioned that fatigue due to extended periods of work at low intensity decreased proprioceptive acuity and impaired motor control. In a study done to compare the effects of local and general fatigue on knee joint position sense indicated that local fatigue to the thigh muscles did not effects any position sense whereas general fatigue protocol of 5 minutes of running at 10 km/h at a 10% uphill grade reduce the joint position sense and increased the angular error (Gear, 2011).

In another research by Ju, Wang, and Cheng (2010) studied on effects of active fatigue movement versus passive repetitive movement on knee proprioception found similar findings as the study of Gear (2011). They also mentioned that after the general loads subjects decreased their ability to reproduce the target joint angles whereas the local loads didn’t affect much on joint position sense. They also stated that fatigue for the active components in the muscle is due to muscle acidosis which might the reason for the failures of muscle spindle and Golgi tendon organs leading to decrease in proprioception. The passive component to the muscle fatigue is due to repetitive movements and tractions while exercising which may cause ligament laxity and failure of mechanoreceptors. This study supported that central fatigue lead to the deterioration of proprioception due to the deficiency if the central processing of proprioceptive signals (Ju, et al., 2010). Another study taken by Abd-Elfattah, Abdelazeim, and Elshennawy(2015) reported that after the general fatigue load there has been statistically noticeable effect on knee proprioception. They found 15% decrease in knee proprioception in knee flexion and extension. They also suggested that decrease in proprioception after the general load is due to decrease of central processing of proprioceptive signals. The central fatigue will decrease the motor control precision; obstruct voluntary muscle stabilizing activity to resist imparted joint forces.

Effects of Local Fatigue on Proprioception:

In a research conducted by Han and Lee to study the effects of kinesiology taping on repositioning error of the knee joint after quadriceps muscle fatigue stated that local muscle fatigue has negative effect on joint proprioception as local muscle fatigue increases the threshold of muscle spindle discharge, affecting afferent feedback and as a result changing knee joint awareness (Han & Lee, 2014). In a study done to find out the effects of exercise and muscle fatigue on shoulder proprioception showed that fatiguing exercise can significantly decrease joint position sense. Their explanation of decrease in joint position sense after muscle fatigue is due to the decline in the capsular receptors sensitivity (Carpenter, Blasier, &Pellizzon, 1998). In a study by Vafadar, Cote, and Archambault that focused on the extent to which muscle fatigue could change the position sense in upper extremity in health adults performing reaching found that there is a change in position sense after muscle fatigue in upper extremity and also a noticeable rise in the signal amplitude seen at the end of exercise indicates muscle fatigue. They also stated that in two different experiments shoulder and elbow with both eccentric and concentric exercises showed a noticeable position sense error after muscular fatigue. They suggested that the decrease in proprioception occurs after fatigue as the mechanoreceptors in the muscles around the joint become dysfunctional and inefficient (Vafadar, et al., 2012).

Effects of Local Muscle Fatigue on Motor Learning:

Cotton, Spieth, Thomas and Biasiotto (1974) researched on local and total body fatigue effects on learning and performance of a gross motor skill. In the study subjects were allotted into three groups- total body fatigue group, local fatigue group and rest group. The results in the study indicated that there was impaired performance by both the local and total body physical fatigue, but the learning is not effected by both the groups. The results also showed that there was significant learning in all the groups, however with the severe exercise there was significant decrements of learning. Therefore the results were not clear about effects of learning due to fatigue and there is not much research or other studies done to support this study. More detailed research is required to know the effects of local muscle fatigue on motor learning. (Cotten, et al.).

Surface EMG evaluation on fatigued muscle:

The evaluation of the local muscle fatigue while performing dynamic work by measuring the myoelectric activity of local muscle using the method of surface electromyography (sEMG) is more advantageous then by determining muscle fatigue using lactate concentration values in the blood samples taken from the muscle at a predetermined time intervals while doing task as it impossible to observe the state of fatigue in real time and also this type of assessment gives an estimate of global fatigue or central fatigue. Biochemical and physiological changes can also be reflected in the properties of myoelectric signals recorded on the surface of the skin above the muscle during fatiguing contraction (Cifrek, Medved, Tonković, &Ostojić, 2009).

The previous studies done to indicate muscle fatigue by the Surface EMG showed that there is slowing of surface myoelectric signals during static contraction (Cifrek, et al., 2009; Rogers &MacIsaac, 2011). Fatigue is manifested as an increase in the signal amplitude (Cifrek, et al., 2009) and the shift towards the lower frequencies of surface myoelectric signal power spectrum (Dimitrova, Arabadzhiev, Hogrel, &Dimitrov, 2009; Rogers &MacIsaac, 2011). The increase in the amplitude with fatigue is due to decreased muscle fiber propagation velocity, increased motor unit firing rate, recruitment and synchronization (Rogers &MacIsaac, 2011). EMG based muscle fatigue assessment during dynamic contractions showed more increased variability in amplitude and spectral parameters like mean frequency and median frequency then during isometric and constant force fatiguing contractions because of recruitment and de-recruitment of active motor unit in the area of the detecting electrodes, the time varying spatial filters as the muscle changes shape as well as the movement of the innervation zone in relation to the surface electrode (Rogers &MacIsaac, 2011). In the recent studies time-frequency analysis procedures have been used to analyze EMG parameters to estimate muscle fatigue in non-stationary conditions. In one of the studies, the fatigue indices used are the mean and variance of the instantaneous frequency, mean of the frequency variance, spectral median frequency, Dimitrov spectral index of muscle fatigue and amplitude. The results of the study showed new spectral indices is better assessment of local muscle fatigue then the traditionally used EMG median frequency. This study in accord with the previous studies dynamic fatiguing exercise let to neuromuscular fatigue and increase in Surface EMG amplitude decrement in the median frequency (Gonzalez-Izal et al., 2010).

CHAPTER III

EXPERIMENT 1

Previous literature demonstrated mixed results of reduced proprioception due to muscle fatigue. Therefore in this study experiment 1 is used to determine the effects of local muscle fatigue (biceps brachii) on the elbow joint proprioception. Accuracy of the movement and the joint position sense is assessed in this study and compared with the non- fatigue (control group). This experiment was also done to find whether local muscle fatigue had any effect on motor learning or not. The learning effect was found out by the post-test which included retention test and transfer test done after 48 hours of training.

METHOD

Participants:

24 Right handed healthy young adults (age=20-40), Wayne State Student both male and female participated in the study. All the participants were randomly and equally assigned to either experiment (fatigued) or control (non-fatigued) group. There was no upper limb injury, surgery, neurological or medical problem to any of the participants. An informal consent was signed prior to the study.

Apparatus:

A Kinesthesiometer (Model 16014, Lafayette Instrument) was utilized to measure the accuracy of angular position movement (see Figure 1). A weight adjustable dumbbell (Power Block Elite Dumbbells) was used for fatigue protocol (see Figure 2).

Figure 1. Apparatus: Kinesthesiometer

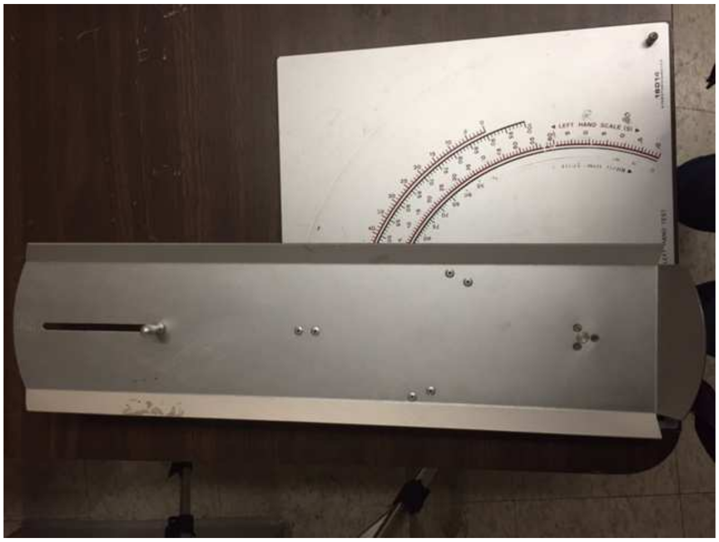


Figure 2. Apparatus: Weight adjustable dumbbells

Fatigue Protocol:

Fatigued protocol for experimental group consisted of biceps curls with dumbbell using 80% of the maximum voluntary contraction. The participants doing the fatigue protocol were asked to stand and perform the protocol making sure the exercise or the curl was performed with elbow flexion and forearm supination. The biceps curls are done until the participants felt unable to do them or 6 to 10 repetitions of the exercise.

Task:

A Kinesthesiometer was placed at a standard desk. Participants were asked to sit comfortably in a chair, facing the table. Their left arm was rested on the Kinesthesiometer handle and a blind fold was used. Participants moved the handle to 3 locations (30, 45 & 60 deg.) in elbow flexion in serial order immediately after they received the go signal. The handle of the kinestheisometer is moved either in slow or quick motion when received the command.

Procedure:

The experiment included 3 stages- pre-test, acquisition and post-test. The participants were familiarized with the task and fatigue protocol before the start of the experiment.

Stage 1- Pre-test: All the participants perform the task for one block without any verbal feedback on the accuracy of the elbow position. One block contained 12 trails of the task. This pre-test values were used to get the base line measure for the study results.

After the pre-test both the experiment and control group were given 2 minutes break before the start of training stage.

Stage 2 - Acquisition (Training) stage: Both the experiment group and control group are made perform 5 blocks which contained 60 trails. The participants in the experiment underwent a fatigue protocol. Each training block followed the fatigue protocol for the experiment group. After the fatigue protocol the participants were made to perform the task immediately without any rest. However between each block after the task was performed they were given 2 minutes rest. The control group did not perform the fatigue protocol. During this stage all the participants were given verbal feedback about the movement accuracy.

Stage 3 - post-test: The post test was conducted after 48 hours of the training stage. It included one block retention test and one block transfer test. The retention test was performed on the same side (left forearm) and the transfer test was performed opposite side (right forearm). Verbal feedback was not given for both the retention and transfer test.

Measurements:

The data collection sheet is designed to record the measured values of all the trails. Each data collection sheet included the information like the condition (control or experiment), Gender (male or female) and the participant were numbered to differentiate from one another. The data collection sheet was also designed such that all the values of all the trails of all the stages (8 blocks) were included in one sheet. All the blocks and trails were named and each trail had a target degree mentioned in the sheet with a blank left beside it to enter the recorded performance value or the raw score of the performance. Once the data is collected from all the participants, then this data was entered into the Microsoft excel sheet. The Excel sheet had columns for subject, gender, sequence, block, trail, score and goal. After all the data was entered into the excel sheet then the data was entered into system for the data analysis.

Primary interest dependent variable was Total Performance Error (E). In equation,

$E = \mathrm{Sqrt}(\sum[X_i - T_i]^2/n)$

Where, X_i = Actual Performance and T_i = Targets

Secondary interest dependent variable was Variable Errors (VE). In equation,

$VE = \mathrm{Sqrt}\ ([X_i - \text{mean}\ X_i]^2/n)$

Where X_i = actual performance.

Two separate Group*Block ANOVAs were used to analyze acquisition and posttest. Also a T-test was employed for pretest. Statistical significance was set at 0.05 levels.

RESULTS

Pretest:

An independent T- Test showed no difference in total performance error ($t=0.01$, $p> 0.05$), and variable error ($t = 2.08$, $p> 0.05$) between experiment and control group.

Acquisition:

Total Errors: A 2 (Group: fatigue vs. control) x 5 (Block) ANOVA with repeated measures on block found practice group effect for both, $F (4, 88) = 10.46$, $P< .01$. Duncan Multiple Range Test (DMRT) indicated movement errors decreased across practice blocks. The main effects of group was significant, $F(1, 22)= 4.91$, $P < .05$, where fatigue conditions ($M=5.73$) produced more error than control ($M= 4.93$). There was no interaction between block and group ($P> .05$).

Variable Errors: A 2 (Group: fatigue vs. control) x 5 (Block) ANOVA with repeated measure on block demonstrated both groups improved accuracy of angular movements as a result of practice, $F (4, 88) = 8.29$, $P<.01$. Duncan Multiple Range Test (DMRT) indicated movement errors decreased across practice blocks. The main effects of group was significant, $F (1, 22) = 5.38$, $P< .05$, where fatigue condition ($M= 5.19$) produced more error than control ($M=4.43$).

Retention and Transfer:

Total Errors: A 2 (Group: fatigue vs. control) x 2 (Block) A separated ANOVA on retention and transfer showed a main effect of group, $F (1, 22) =10.01$, $P<.01$. Further DMRT revealed that fatigue group ($M=8.08$) produced more total error compared to control ($M=5.41$), analysis did not detect difference between retention and transfer, F (1, 22) =1.66, P>.05 or interaction, F (1, 22) = 0.10, p>.05.

Variable Error: With ANOVA, F (1, 22) = 9.50, P < .01. DMRT revealed that fatigue group (M=4.82) produced more variable error than control group (M=3.35).The analysis did not detect difference between retention and transfer, F (1, 22) = 0.26, P> 0.05, or interaction, F(1,22) = 0.00, P> 0.05.

Figure 3. Total Errors in Pre-test, Acquisition, Retention & Transfer

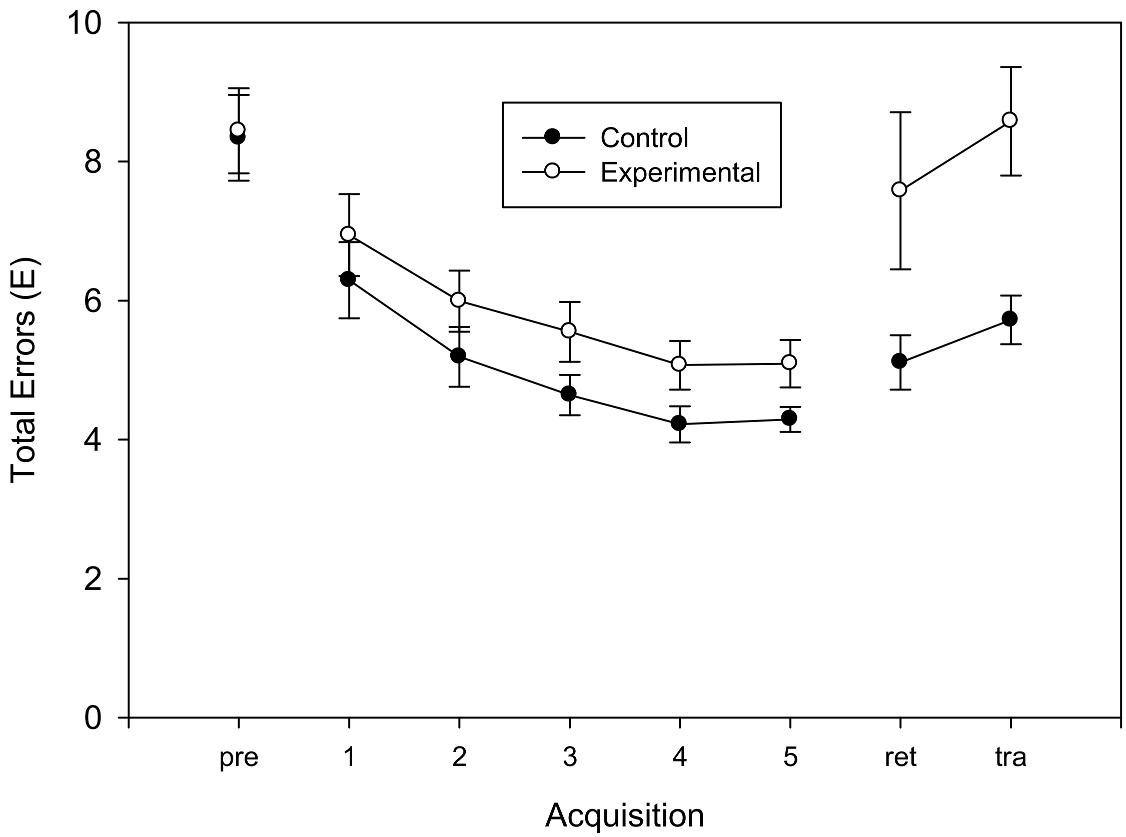
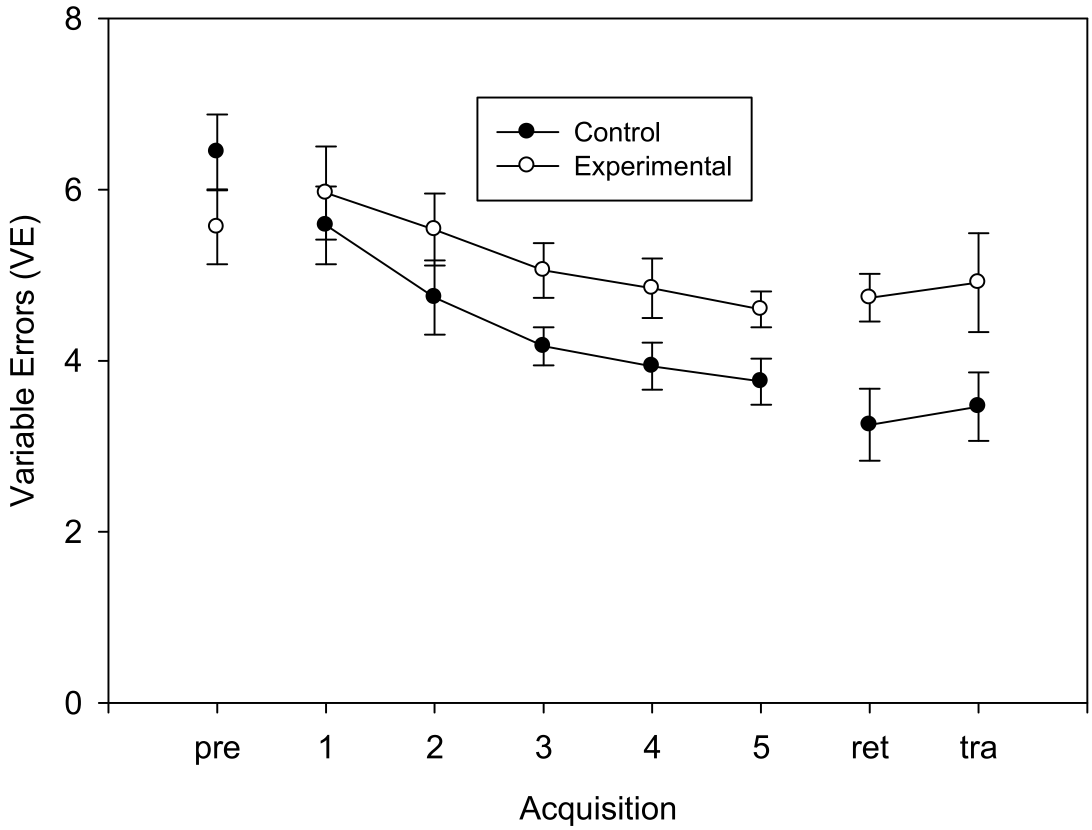


Figure 4. Variable Errors in Pre-test, Acquisition, Retention & Transfer



CHAPTER IV

EXPERIMENT 2

Experiment 2 in the study was used to investigate the changes of neuromuscular recruitments in the fatigued muscle. A within group design was administered for fatigue and non-fatigue conditions. The knowledge and results for the performance was provided to participants for skill acquisition.

METHODS

Participants:

12 college students (age=20-40) from Wayne State University, both male and female participated in the study. All the participants were right handed. There was no upper limb injury, surgery, neurological or medical problem to any of the participants. An informal consent was signed prior to the study.

Apparatus:

A Kinesthesiometer (Model 16014, Lafayette Instrument) was utilized to measure the accuracy of angular position movement (see Figure 1). A weight adjustable dumbbell (Power Block Elite Dumbbells) was used for fatigue protocol (see Figure 2). A Biopac system with surface EMG interface (MP 100) was for recording and measure of the EMG on biceps brachii.

Fatigue Protocol:

Fatigued protocol consisted of biceps curls with dumbbell using 80% of the maximum voluntary contraction. All participant during the fatigue protocol were asked to stand and perform the protocol making sure the exercise or the curl was performed with elbow flexion and forearm supination. The biceps curls are done until the participants felt unable to do them or 6 to 10 repetitions of the exercise.

Task:

A Kinesthesiometer was placed at a standard desk. Participants were asked to sit comfortably in a chair, facing the table. Their left arm was rested on the Kinesthesiometer handle and a blind fold was used. Participants moved the handle to 3 locations (30, 45 & 60 deg.) in elbow flexion in serial order immediately after they received the go signal. The handle of the kinestheisometer is moved either in quick motion when received the command.

Procedure:

This experiment consisted of 6 blocks and each block had 12 trails each. The participants were familiarized with the task and fatigue protocol before the start of the experiment. All the participants performed 6 blocks of the task and fatigue protocol before every other block. Half of the participants randomly selected started the experiment or the block without fatigue protocol. These participants performed fatigue protocol before blocks 2, 4, and 6. And the rest half of the participants performed fatigue protocol before blocks 1, 3, and 5. After the fatigue protocol participants were made to perform the task immediately without any rest. All the participants were given 2 minutes rest after each block. Surface EMG signals of the first three trails (30, 45, 60 degrees) of the all the blocks were recorded using the biopac system. To record the EMG signals two surface electrodes were placed on the biceps brachii muscle. One electrode was placed on the muscle belly and the other was placed three finger width below the first electrode.

Measurement:

Data collection sheet was designed for this experiment. The sheet was designed for 6 blocks which included 12 trails. The performance data for all the trails was recorded in the data collection sheet. Each block was numbered and prefix was added to mark if the block was followed by fatigue protocol or not. The EMG signals for the first three trails of the every block were recorded and processed through AcqKnowledge software. The frequency and integral (amplitude) of the signals was assessed and through the software the wave form of the signals is converted into numerical values. For each EMG data of the first three trails, time frequency, area and integral were calculated. All the EMG data and performance data are entered into two separate Microsoft excel spread sheets.

RESULTS

One way ANOVA with repeated measure on condition revealed a main effect of Integral EMG (amplitude), $F(1, 12) = 6.14$, $P < .05$, where the fatigue condition ($M = 14.06$) produced significantly less EMG area than non-fatigue condition ($M = 25.42$). A main effect of the EMG frequency was also significant, $F(1, 22) = 7$, $P<.05$, where fatigue condition ($M = 3.37$) was greater than non-fatigue ($M = 2.41$).

CHAPTER V

GENERAL DISCUSSION AND CONCLUSION

This study was designed to examine the effects of local muscle fatigue on proprioception and also to investigate local muscle fatigue effects on motor learning. Experiment 1 utilized pretest, acquisition, retention and transfer test to inspect proprioception and motor learning effects after local muscle fatigue. The results showed movement error in both total error (TE) and variable error (VE) is reduced across practice blocks, but the fatigue conditions produced more error than control in the acquisition test. In retention and transfer test both TE and VE is more in fatigue group when compared to control group. These results indicated that there is a decline in proprioception and negative effects on motor learning due to local muscle fatigue.

Various mechanisms explaining the underlining mechanism of fatigue and its effects in proprioception are, according to Ju et al. (2010), when the metabolic products like lactic acid increase rapidly after the muscle contraction in local muscle fatigue state activate nociceptors and cause inflammation. These metabolites and inflammation has direct effect on the discharge method of muscle spindle, along with this the anaerobic system of muscle fatigue causes muscle acidosis and decline in muscle performance (Ju et al., 2010). According to Dimitrova et al. (2009) in their research study stated the when the muscle contraction force attains 60% maximum voluntary contraction or more then there was increased slope in the rate of changes in spectral index value. They found that blood flow in the human muscles ex. biceps brachii is extremely limited for forces higher than 30% maximum voluntary contraction. Therefore during the peripheral muscle fatigue when the force of maximum voluntary contraction is 60% or more, then the muscle will be hypoxic condition. In the hypoxic condition there is lack of ATP supply in the muscle fiber leading to the dysfunction of ATP dependent Ca^{2+} pump of the sarcoplasmic reticulum of the muscle. This causes reduction in the uptake of Ca^{2+} and accumulation, elevation of the resting free Ca^{2+} concentration. This causes significant rise in fatigability of fast muscle fibers when compared to slow twitch muscle fiber (Dimitrova, Arabadzhiev, Hogrel, &Dimitrov, 2009). In another study done to find the effects of different levels of localized muscle fatigue on knee position sense also found that thigh muscle mainly composed of fast twitch muscle fibers fatigue faster than slow twitch muscle fibers(Gear, 2011).

Generally after severe exercise we feel awkward, graceless and not sure where we placed our fatigued limbs without looking at them. This might be due to disorder in proprioception due to fatigue. Muscle fatigue is just not exhaustion of muscle energy sources but also involve spinal and cortical levels (Proske&Gandevia, 2012). In a study by Marks R on “effects of exercise induced fatigue on position sense of the knee” found that after intensive activity the postural sensation of the knee is decreased. They stated that position sensitivity after fatigue is due to activation of other muscles and their muscle spindles, activation of inhibitory afferents from chemo sensitive group III and IV fibers and presynaptic inhibition which differs the frequency of alpha motor neurons discharge and their recruitment. A decrease in fusimotor-driven feedback due to group III and IV non spindle muscles after fatigue may also cause sensitivity changes of large-diameter proprioceptive afferents and their spinal reflex efficacy (Marks, 1994). Another author Vafadar, Cote and Archambault in his article mentioned that malfunction of joint and muscle receptors after fatigue causes changes in the position sense (Vafadar, et al., 2012). A similar study done by Lee, Liau, Cheng, Tan and Shih on evaluation of shoulder proprioception following muscle fatigue found that proprioception is more effected with shoulder external rotation then internal rotation as with external rotation capsular ligaments and rotator cuff muscles tighten causing decreased in sensitivity of capsular receptors then that of shoulder internal rotation (Lee, et al., 2003). Disturbed proprioception can have negative effects on feedback and feed forward motor control, sensorimotor control and the regulation of muscle stiffness (Röijezon, Clark, &Treleaven, 2015) and with very intense exercise there is a noticeable decrease in learning (Cotten, Spieth, Thomas, &Biasiotto, 1974) and decline in proprioception effects motor learning by affecting the internal forward model of motor command (Röijezon, Clark, &Treleaven, 2015). Very limited study is done on fatigue effects on motor learning therefore there is more scope of research in this field.

Experiment 2 was designed to understand the mechanism of muscle fatigue using the sEMGto compare the neuromuscular recruitments on the biceps between fatigued and non-fatigued conditions. The results showed that the frequency was increased and amplitude (or integral EMG) was decreased in fatigued condition when compared to non-fatigued. Results of the present study on sEMG were contrary to some of the previous research as their results showed increased amplitude and decreased frequency in the fatigued muscle. The increase in amplitude and decrease in frequency was imputed to increased motor unit recruitment and additional spatial and temporal motor unit synchronization to counteract muscle fiber fatigue (Gonzalez-Izal, et al., 2010). Remarkably, the difference in the results of the present study and the previous research could be due to the task difference. The task of the previous studies required more muscle force such as maximum (or sub-maximum) contraction when compared to the present study task with a low force demand. The present finding appeared the neuromuscular system tended to increase rate code (or frequency) to counter a degraded efficiency for motor unit recruitments caused by fatigue. In summary, this study would help in better understanding of effects of local muscle fatigue in proprioception and motor learning.

APPENDIX

WAYNE STATE UNIVERSITY

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NOTICE OF EXPEDITED APPROVAL

To: Gowtami Datla
Kinesiology, Health and Sport Studies
Office of International Studen

For
From: Lawrence R. Crane, M.D. or designee D Bulawski IRB
Chairperson, Medical Institutional Review Board (M1)

Date: March 16, 2015

RE: IRB #: 124214M1E
Protocol Title: Effects of Local Muscle Fatigue on Proprioception and Motor Learning
Funding Source:
Protocol #: 1412013655

Expiration Date: March 15, 2016

Risk Level / Category: Research not involving greater than minimal risk

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The above-referenced protocol and items listed below (if applicable) were **APPROVED** following *Expedited Review* (Category (4)* (7)*) by the Chairperson/designee *for* the Wayne State University Institutional Review Board (M1) for the period of 03/16/2015 through 03/15/2016. This approval does not replace any departmental or other approvals that may be required.

- Revised Protocol Summary Form (received in the IRB Office 2/27/15)
- Revised Protocol (received in the IRB Office 2/27/15)
- Medical Research Informed Consent (revision dated 2/17/15)
- Recruitment Script

- Federal regulations require that all research be reviewed at least annually. You *may* receive a *"Continuation Renewal Reminder"* approximately two months prior to the expiration date; however, it is the Principal Investigator's responsibility to obtain review and continued approval ***before*** the expiration date. Data collected during a period of lapsed approval is unapproved research and can never be reported or published as research data.
- All changes or amendments to the above-referenced protocol require review and approval by the IRB **BEFORE** implementation.
- Adverse Reactions/Unexpected Events (AR/UE) must be submitted on the appropriate form within the timeframe specified in the IRB Administration Office Policy (http://www.irb.wayne.edu//policies-human-research.php).

NOTE:

1. Upon notification of an impending regulatory site visit, hold notification, and/or external audit the IRB Administration Office must be contacted immediately.
2. Forms should be downloaded from the IRB website at each use.

*Based on the Expedited Review List, revised November 1998

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ABSTRACT

EFFECTS OF LOCAL MUSCLE FATIGUE ON PROPRIOCEPTION AND MOTOR LEARNING

by

GOWTAMI DATLA

May 2016

Advisor: Dr. Qin Lai

Major: Kinesiology and Exercise Science

Degree: Master of Education

Background: Muscle fatigue is an exercise induced decline in the ability of muscles to produce force or power. Recent studies showed that decline in proprioception due to fatigue lead to an increasing risk of falls and injury. However, it was unknown whether fatigue-induced proprioception decrease affects skill acquisition and memory consolidation. Purpose: The aim of the study was to investigate the effects of local muscle fatigue on perceptual motor learning in arm positioning task and to compare surface EMG activities in the fatigue and non-fatigue muscle conditions. Two experiments were used to investigate the purpose. In Experiment 1, Methods: 24 healthy young adults (Age: 20-40) were randomly and equally assigned into either control or experiment group. An informed consent was signed prior to the study. Both the groups performed the same task but the experiment group underwent a fatigue protocol (biceps curls with weight of 80% voluntary contraction until fatigue) during the acquisition phase. The task was to place the left forearm on a kinestheiometer and moved the handle to 30, 45, 60 degrees by flexion. All the participants performed 1 block of pre-test, 5 blocks of acquisition phase, 1 block

of post-immediate test during the first visit. A delayed retention and bilateral transfer tests were administered 48 hrs after the first visit. Each block had 12 trials. Throughout the task participants were blind folded and were given verbal feedback during the acquisition only. Results: A 2 X 5 (Group vs. Block) ANOVA with repeated measure on Block for acquisition demonstrated both groups decreased total movement error (E) with practice, $F(4, 88) = 10.46$, $p<.01$. A main effect of group was detected, $F(1, 22) = 4.91$, $p<.05$. Duncan's MRT indicated fatigue group (M=5.73) produced more E relative to the controlled (M=4.93).A separated ANOVA for retention, and transfer tests also detected a main effect of group, $F(1, 22) = 10.19$, $p<.01$ for total error. DMRT revealed that fatigue group (M=8.08) produced more variable error than control group (M=5.41). The analysis did not detect difference between retention and transfer [$F (1, 22)= 0.26$, $P> 0.05$] or interaction [$F (1, 22) = 0.00$, $P> 0.05$]. In Experiment 2, Methods: 12 healthy individuals (age 20-40) participated in the experiment that consisted of 6 blocks with 12 trials each. All the participants performed 6 blocks of task and fatigue protocol before every other block. After fatigue protocol participants were made to perform the task immediately without rest but were given 2 minutes rest after each block. Results: One way ANOVA with repeated measure on condition showed a main effect of fatigue for the EMG frequency, $F (1, 22) = 7$, $P<.05$. Where fatigue condition was greater than non-fatigue. The main effect was also detected for the integral EMG (amplitude), $F (1, 12) = 6.14$, $P< .05$, where non fatigue was greater than fatigue. Conclusion: Both the control and experiment group exhibited perceptual motor learning with practice. The fatigue group showed a greater error than the control group in acquisition, retention and transfer. The surface EMG showed increased frequency and decreased integral (amplitude) in the fatigued muscle when compared to non-fatigue condition. In summary, local muscle fatigue had negative effects on perceptual motor acquisition and memory consolidation by degrading proprioception and efficiency on the muscles.

AUTOBIOGRAPHICAL STATEMENT

My full name is Gowtami Datla. I am an Indian nationality who has come to The United States of America to pursue my dreams of higher education in the elite universities here. I had earlier done my Bachelors in Physiotherapy from VAPMS College, located in the beautiful coastal city, Visakhapatnam, India. Born into a middle income family, education was priority. Choosing the field of education immediately after high school was a herculean task. Though many suggested various other fields like engineering, arts etc., I listened to my heart and interest, which always pinned towards medical field. Going forward, with immense support from my family, in 2003, I chose Biological Sciences group and later in 2005, Physiotherapy, as my field of study.

I graduated from Bachelors in Physiotherapy in 2011, after which I worked in many hospitals, the prominent among them being ‘Seven Hills’, Visakhapatnam. Working there gave me the best insight into the practical use of Physiotherapy on human kind. There was still, a lot to probe. Where best to start, in order to quench the thirst of inquisitiveness – USA. Higher education and research in Kinesiology and Exercise Science led me to Wayne State University. During my stay at WSU, I learnt a lot about motor control and learning, and researched in motor learning and proprioception under fatigue conditions. This finally brought me very close to the insight, which I wanted to attain, after coming to USA. I am thankful to the faculty and staff at WSU, for their generous continued support in helping me fulfill my dream and satisfy my thirst for knowledge. Now, I take it as my duty to put my knowledge into action and serve the society in the best way possible.

I am single. My parents stay in Visakhapatnam, India. I have a younger brother, who is into Commercial Navy. After I graduate from WSU, I am planning to work full time in the field of Physiotherapy. I look forward to my upcoming opportunities and challenges.