SUPERIMPOSED DIRECT AND ALTERNATING CURRENT ON MAXIMUM VOLUNTARY ISOMETRIC TORQUE PRODUCTION AND ELECTROMYOGRAPHIC ACTIVITY

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INTRODUCTION

Neuromuscular electrical stimulation (NMES) is a widely accepted exercise technique used to supplement maximum voluntary contractions (MVC) and increase muscular torque production [1-3]. Within the rehabilitative setting, NMES has been used to neuromuscularly re-educate, restore and optimize motor unit recruitment inhibited post-surgery or via pathology [4-9]. Muscular inhibition normally exists within different muscle groups during MVC relative to age, individual motivation, and training level [8, 10]. Training asymptomatic individuals via superimposed NMES and voluntary contractions enhances torque production by increasing motor unit recruitment [11, 12]. Superimposed alternating current involving trained and untrained subjects coupled with concentric and/or eccentric exercise has been proven to increase muscular torque production more than exercise alone [11, 12]. However, a review of ten superimposed NMES training studies revealed inconclusive and controversial results and only one of the studies involved direct current NMES superimposed during isokinetic training and results indicated torque production was not different than voluntary contractions alone [13-17]. Recommendations of these studies include electromyography (EMG) assessment to help determine the mechanisms of superimposed muscular activity on increases in strength or power [18]. Unfortunately, to our knowledge EMG has not been utilized to assess the effects of direct or alternating current NMES with superimposed contractions. Additionally, no studies have utilized isometric exercise superimposed with direct current.

Therefore the purpose of this study was to investigate the effect of superimposed direct and alternating current on quadriceps femoris isometric torque production via

EMG assessment following a six-week training period with healthy intermediately trained subjects. It was hypothesized that isometric torque training superimposed with direct or alternating current will elicit greater motor unit recruitment resulting in increased torque production when compared to controls.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

A single blind randomized 3 x 3 ANOVA with repeated measures (RM) was used to analyze the effect of isometric exercise with superimposed NMES direct and alternating current had on intermediately trained participants at a 60 degree knee flexion angle following a six-week training period. Independent variables consisted of: group [Direct Current (DC), Alternating Current (AC) and Control (CON)]; and test (PRE, MID, and POST training periods). Dependent variables consisted of thigh girth (at 5, 10, 15, & 20 cm from the superior pole of the patella), quadriceps femoris isometric torque production at 60 and 90 degrees of knee extension, and integrated electromyographic (iEMG) activity of the quadriceps femoris (vastus medialis (VM), vastus lateralis (VL), and rectus femoris (RF)) muscles.

PARTICIPANTS

Participants were 30 healthy intermediately resistance trained male volunteers aged 18 to 34 years of age (23 ± 3.1 yrs) from the university and greater local community. Participant demographics are listed in Table 1. The American College of Sports Medicine (ACSM) classification of intermediately trained participants is defined as six months of consistent resistance training [19, 20]. All volunteers were screened by a medical doctor prior to the study via a Pre-participation Medical History and Physical Activity Readiness Questionnaire (Appendix D). Study exclusionary criteria included history of knee surgery, knee injury, pacemaker, history of blood clots, neurological disease, cardiopulmonary disease, and exercise contraindications outlined by the ACSM (Appendix C), or the stated inability to complete the study. All volunteers signed an informed consent form approved by the Universities Human Studies Program prior to participating in study (Appendix A).

PROCEDURES

Experimental Protocol Overview

All data collection and isometric training were conducted in the University's Athletic Training Education laboratory by the same National Athletic Trainers' Association Board of Certification (BOC) Certified Athletic Trainer (ATC). The ATC randomly assigned each single blinded training group: Isometric quadriceps contraction superimposed with direct current (DC), isometric contraction superimposed with alternating current (AC), and isometric contraction only (CON), and collected all measurement data [thigh girth, isometric torque, and iEMG]. All participants were familiarized with the data collection and training procedures prior to the start of the study. Anthropometric data, including blood pressure (mmHg) were assessed and a five-minute cycle ergometer warm-up was provided before all data collection tests and training sessions. All test data and training conditions were administered to participants' right legs. Prior to all Maximum Voluntary Isometric Contraction (MVIC) data collection tests and training sessions participants completed four ten-second (duration) isometric contractions at 50, 60, 80, and 90% of their MVIC torque outputs followed by a two minute rest period. Participants were instructed to maximally extend their knees against the Biodex knee attachment arm for a ten seconds duration after which a three-second countdown was used to initiate MVIC data collection and training.

Data collection tests: consisted of circumference assessment of the right thigh relaxed and maximally contracted with a "Gulick" tape measure at 5, 10, 15, and 20 cm above the superior pole of patella (See Appendix J); MVIC of quadriceps extension torque was assessed randomly at 60 and 90 degrees of knee flexion on a Biodex System 3 Pro dynamometer (Biodex Medical Systems, Inc., Shirley, New York); surface integrated electromyography (iEMG) activity was assessed during MVICs with a Biopac MP30 EMG device (BIOPAC Systems, Inc., Santa Barbara, CA). Electromyographic signal data were captured at 2,000 Hz with the gain set at 2,500 Hz and a band pass filter set at 30-500 Hz and stored for analysis with Acknowledge software from the vastus lateralis (VL), the rectus femoris (RF), and vastus medialis (VM) muscles. Data were collected at baseline (PRE/Pre-test), after three weeks of training (MID), and at the end of the six week training period (POST). Quantified muscular activity recording were presented as mean and peak integrated signals measured in microvolts (μV). Single blinding participants involved placement of a standard cardboard box over the DC and AC stimulators during all training sessions. Testing involved two randomly ordered MVICs at 60 and 90 degrees of knee flexion. No subsequent verbal, visual, or tactile encouragement was provided during data collection test periods.

Training: ***Maximal Voluntary Isometric Contraction (MVIC)*** training was initiated within two days of the familiarization and pre-test data collection period. Training consisted of 10 MVIC quadriceps extension repetitions at 60 degrees of knee flexion for a five second duration (hold), and three sets, separated by two-minute rest periods, three times per week, for six weeks. Each supervised training session lasted approximately 20 minutes. Both DC and AC groups trained concurrently with superimposed electrical stimulation. Superimposed NMES intensity was adjusted for each subject via a ***Visual Analog Pain Scale (VAPS)*** as natural electrical stimulation accommodation occurred. Superimposed direct current was administered with an ***Accelerated Recovery Performance RX100*** (ARP) (Apple Valley, MN) ***stimulator***. Alternating current was administered with a ***Forte 200 Stimulator*** (ACS) (DJO LLC, Vista, CA). The VAPS was utilized to ensure that no pain was experienced with stimulation following any changes in stimulation intensity (Appendix E). Electrical stimulation remained on during exercise and rest periods. During the rest periods, participants were given an option to increase stimulation intensity as accommodation to stimulation occurred [22, 23]. Initial stimulation intensity, as well as any changes in stimulation intensity was recorded on an electrical stimulation intensity form (Appendix F and G). A sham stimulator was not utilized to blind the CON group during training sessions. The CON group performed identical quadriceps exercise, repetitions, and sets without electrical stimulation.

Stimulation intensity was based on participant's perceived stimulation comfort and was increased accordingly to the strongest current intensity tolerated without experiencing pain. A standardized script was read to subjects to facilitate the achievement of adequate electrical stimulation intensity without causing pain (see Appendix I).

Surface Integrated EMG Measurement (iEMG) Electrode placement. Prior to electrode placements on the right thigh vastus lateralis (VL), rectus femoris (RF), and vastus medialis (VM), skin surfaces were shaved then alcohol pads and coarse sponges were used to slightly abrade the electrode placement sights for optimal electrical contact. Skin impedance was measured with the electrode checker function on the electromyography unit and only values below 50 kilo-ohms were accepted [21]. Participants were positioned supine on a treatment table with right leg in full extension. The VL reference point was marked at 50 percent of distance between the most prominent point of the greater trochanter and the lateral femoral epicondyle (54) (Appendix K). The RF reference point was marked at the midpoint between the anterior superior iliac spine and apex of patella (Appendix K). The VM reference point was marked at 20 percent of the distance between the medial knee joint line and the anterior superior iliac spine (Appendix K). Negative and positive electrodes were placed 1 cm proximal and distal respectively from each reference point (2 cm inter-electrode distance). The ground electrode was placed on the contralateral tibia, 6 centimeters inferior to the tibial tuberosity (Appendix K). Electrode placements were recorded via tracings on a transparent plastic template to ensure reproducibility among the three data collection test periods.

DC and AC Electrode Placement Electrode placement for DC and AC groups was based on quadriceps motor points determination via minimal DC intensity with maximal motor unit recruitment of the VL, RF, VM. Motor point replication and subsequent electrode placement was established with a transparent plastic template tracing and bony landmark location (i.e. superior patella border and femoral triangle) for replication during training. Following AC or DC electrode placement (positive, negative

& ground) a standard large goniometer was used to place the right knee at 60 degrees of flexion with subsequent Biodex goniometer matched adjustment.

Biodex Dynamometer Protocal for MVIC Measurement. Prior to MVIC assessment of each subject the Biodex was calibrated to ensure data reliability. The Biodex seat back was adjusted via a standard large goniometer to allow 110 degrees of hip flexion relative to the midline of the trunk. Participant's arms were crossed upon their chests and two "Velcro" straps were used to stabilize the upper torso over their crossed arms, two additional "Velcro" straps were used to secure the hips and right thigh to the Biodex chair to provide stability and to prevent substitution (Appendix L). The axis of rotation of the knee extension attachment arm was aligned with the most prominent point of the lateral femoral epicondyle (knee axis). The knee extension attachment limb pad was adjusted to accommodate the participant's leg length and adjusted to prevent dorsiflexion limitation of the ankle joint. Adjustable components of the dynamometer were recorded on a Biodex positioning sheet (Appendix H) to ensure replication among data collection test periods. Once secured, participant's knee range of motion while seated was assessed via a standard large goniometer and recorded via Biodex software. Gravity correction was calibrated with the right knee fully extended (180 degrees) to account for limb weight.

STATISTICAL ANALYSIS

Descriptive statistics including means, standard deviations, and ranges were generated for all demographic characteristics and variables of interest. The statistical model for this prospective study included individual 3 x 3 repeated measures analysis of variance (ANOVA) with repeated measures (RM) for each dependent variable (Limb Girth [5, 10, 15, and 20 cm non-contracted/ contracted], MVIC [60 and 90 degrees], and iEMG of rectus femoris, vastus lateralis, and vastus medialis). Mauchly's Test of Sphericity was performed to ensure variance between groups were equal. If the assumption of sphericity was violated an adjustment was made with Greenhouse-Geisser Correction. A second analysis was performed using a one-way ANOVA to compare means between testing periods (PRE to MID, MID to POST, and PRE to POST). All statistical analyses were completed using SPSS v 20.0 (IBM, Armonk, NY, USA) with the alpha level set at $p < 0.05$. When results were significant, a Tukey's honestly significant difference test was performed.

RESULTS

Participant demographic data for each data collection period are listed in table 1.

Table 1: Mean and Standard Deviation of Participant Demographics

Mean and Standard Deviation of Participant Demographics

	PRE-TEST		
	DC	AC	CON
Age (yrs)	23.60 ± 3.06	23.90 ± 1.96	23.70 ± 4.22
Height (cm)	177.95 ± 2.78	178.04 ± 7.09	180.68 ± 7.62
Body Mass (kg)	75.33 ± 10.54	77.75 ± 13.38	88.35 ± 12.89
	MID-TEST		
	DC	AC	CON
Age (yrs)	23.60 ± 3.06	24.00 ± 2.05	23.90 ± 4.04
Height (cm)	178.05 ± 2.92	178.29 ± 7.18	181.35 ± 7.87
Body Mass (kg)	76.16 ± 10.03	81.44 ± 11.35	88.01 ± 13.11
	POST-TEST		
	DC	AC	CON
Age (yrs)	23.90 ± 2.88	24.00 ± 2.05	23.90 ± 4.04
Height (cm)	178.10 ± 2.93	178.14 ± 6.87	180.82 ± 8.15
Body Mass (kg)	76.05 ± 9.83	81.68 ± 11.40	87.69 ± 13.79

Mean ± Standard Deviation, DC= Direct Current AC= Alternating Current, CON= Control, Yrs=Years, cm= centimeters, kg=kilograms

Muscular Strength

Maximum voluntary isometric contraction mean and standard deviation values for each test period and group are presented in Table 2. Mauchly's test indicated that the assumption of sphericity was violated for MVIC at 60 degrees (MVIC60), $\chi^2(2) = 14.158$, $p<.05$. A Greenhouse-Giesser estimate of sphericity corrected the degrees of freedom, $\varepsilon = .704$, for the main effect of test period with MVIC60. No significant main effects were revealed among groups ($p>0.05$) at 60 or 90 degrees. A significant main effect for test period was revealed for both MVIC60, $F_{(1.4, 38.03} = 43.61$, $p<0.0001$ and MVIC at 90 degrees (MVIC90), $F_{(2, 54)} = 7.08$, $p=0.002$ (See Table 2). Contrasts revealed MVIC60 significantly differed from PRE to MID, $F_{(1, 27)} = 39.02$, $p<0.0001$ and from MID to POST, $F_{(1, 27)} = 19.02$, $p<0.0001$. However, contrasts with MVIC90 resulted in a significant difference only from PRE to MID, $F_{(1, 27)} = 10.74$, $p=0.003$. No significant test period interactions or main effects for condition with either MVIC test position ($p>.05$) were found. A one-way ANOVA revealed no significant difference between MVIC60 and MVIC90 means ($p>.05$).

Table 2: Mean and Standard Deviation of Maximum Voluntary Isometric Contraction at 60 and 90 Degrees

Mean and Standard Deviation of MVIC at 60 Degrees (ft. lbs.)			
	PRE	MID	POST
DC	140.4 ± 24.6	171.4 ± 23.5*	187.7 ± 31.8**
AC	142.8 ± 31.4	181.3 ± 35.3*	198.7 ± 48.9**
CON	168.2 ± 40.9	208.9 ± 52.7*	226.4 ± 59.1**
Mean and Standard Deviation of MVIC at 90 Degrees			
	PRE	MID	POST
DC	156.5 ± 35.1	171.9 ± 34.5*	173.6 ± 36.5*
AC	151.6 ± 51.0	173.7 ± 48.8*	177.2 ± 56.6*
CON	185.6 ± 68.2	228.8 ± 68.4*	217.2 ± 56.5*

MVIC = Maximum Voluntary Isometric Contraction (Values measured in Foot-Pounds), MVIC ± Standard Deviation , DC= Direct Current, AC= Alternating Current, CON= Control * Statistically Significant p < .05 from PRE; **Statistically Significant from PRE and MID

Neuromuscular Activation

Integrated EMG mean and standard deviation values for each test period and group are presented in Tables 3, 4, 5, and 6. These iEMG signals are presented in Figures 9, 10, and 11. No significant main effects were revealed among groups ($p>0.05$) at 60 or 90 degrees. A significant main effect of data collection test period was noted with vastus lateralis at 60 degrees (VL60) mean, $F_{(2, 54)} = 24.19$, $p<0.0001$ and peak values, $F_{(2, 54)} = 17.45$, $p<0.0001$ (See Table 5). Contrasts revealed iEMG values of

VL60 mean, $F_{(1, 27)} = 27.57$, $p<0.0001$ and peak, $F_{(1, 27)} = 19.88$, $p<0.0001$ significantly differed from PRE to MID (See Figures 3 and 4). Similarly, a significant main effect of test period was also observed with vastus lateralis at 90 degrees (VL90) mean, $F_{(2, 52)} = 12.20$, $p<0.0001$ and peak values, $F_{(2, 52)} = 8.85$, $p<0.0001$ (See Figures 7 and 8). Contrasts indicated significant differences from PRE to MID with mean, $F_{(1, 26)} = 21.83$, $p<0.0001$ and peak, $F_{(1, 26)} = 14.91$, $p<0.001$, measurements.

Similarly, a significant main effect of test period resulted from mean and peak iEMG values of rectus femoris ($F_{(2, 54)} = 9.96$, $p<0.0001$ and $F_{2, 54)} = 5.78$, $p<0.0001$ respectively) and vastus medialis ($F_{(2, 54)} = 5.788$, $p<0.005$, and $F_{(2, 54)} = 5.36$, $p=0.007$, respectively) at 60 degrees. Contrasts indicated increases in mean ($F_{(1, 27)} = 8.08$ and $F_{(1, 27)} = 6.21$, respectively) and peak ($F_{(1, 27)} = 11.61$ and $F_{(1, 27)} = 5.02$, for rectus femoris and vastus medialis, respectively) values from PRE to MID (See Figures 1, 2, 5, and 6). No significant differences were observed with rectus femoris and vastus medialis iEMG measurements at 90 degrees ($p>.05$). A one-way ANOVA revealed no significant mean differences with any of the iEMG variables ($p>.05$).

Table 3: Mean and Standard Deviation of Rectus Femoris Integrated Electromyography at 60 Degrees

Mean and Standard Deviation Rectus Femoris Mean iEMG at 60 Degrees (mV)			
	PRE	MID	POST
DC	0.38 ± .18	0.46 ± .12 *	0.54 ± .16
AC	0.37 ± .11	0.55 ± .21 *	0.51 ± .17
CON	0.44 ± .28	0.49 ± .23*	0.58 ± .26
Mean and Standard Deviation Rectus Femoris Peak iEMG at 60 Degrees			
	PRE	MID	POST
DC	0.72 ± .27	0.89 ± .23 *	0.96 ± .23
AC	0.70 ± .20	1.03 ± .35 *	0.98 ± .47
CON	0.83 ± .50	1.02 ± .47 *	1.09 ± .47
Mean or Peak Integrated Electromyography (measured in millivolts) ± Standard Deviation, DC= Direct Current, AC= Alternating Current, CON= Control, * Statistically Significant p < .05			

Table 4: Mean and Standard Deviation of Vastus Medialis Integrated Electromyography at 60 Degrees

Mean and Standard Deviation Vastus Medialis Mean iEMG at 60 Degrees			
	PRE	MID	POST
DC	0.32 ± .14	0.42 ± .17 *	0.49 ± .27
AC	0.34 ± .24	0.40 ± .15 *	0.35 ± .19
CON	0.32 ± .22	0.35 ± .18 *	0.45 ± .26
Mean and Standard Deviation Vastus Medialis Peak iEMG at 60 Degrees			
	PRE	MID	POST
DC	0.63 ± .26	0.76 ± .30 *	0.89 ± .49
AC	0.60 ± .32	0.71 ± .23 *	0.63 ± .39
CON	0.61 ± .38	0.65 ± .32 *	0.81 ± .44
Mean or Peak Integrated Electromyography (measured in millivolts) ± Standard Deviation, DC= Direct Current, AC= Alternating Current, CON= Control, * Statistically Significant p < .05			

Table 5: Mean and Standard Deviation of Vastus Lateralis Integrated Electromyography at 60 Degrees

Mean and Standard Deviation Vastus Lateralis Mean iEMG at 60 Degrees			
	PRE	MID	POST
DC	0.26 ± .07	0.38 ± .10 *	0.41 ± .14
AC	0.23 ± .05	0.31 ± .08 *	0.32 ± .05
CON	0.22 ± .13	0.25 ± .10 *	0.28 ± .15
Mean and Standard Deviation Vastus Lateralis Peak iEMG at 60 Degrees			
	PRE	MID	POST
DC	0.46 ± .13	0.64 ± .21 *	0.68 ± .27
AC	0.39 ± .08	0.53 ± .13 *	0.55 ± .12
CON	0.39 ± .24	0.42 ± .14 *	0.46 ± .25
Mean or Peak Integrated Electromyography (measured in millivolts) ± Standard Deviation, DC= Direct Current, AC= Alternating Current, CON= Control, * Statistically Significant $p < .05$			

Table 6: Mean and Standard Deviation of Vastus Lateralis Integrated Electromyography at 90 Degrees

Mean and Standard Deviation Vastus Lateralis Mean iEMG at 90 Degrees			
	PRE	MID	POST
DC	0.32 ± .11	0.46 ± .17 *	0.44 ± .15
AC	0.26 ± .08	0.34 ± .08 *	0.32 ± .06
CON	0.28 ± .21	0.31 ± .15 *	0.32 ± .26
Mean and Standard Deviation Vastus Lateralis Peak iEMG at 90 Degrees			
	PRE	MID	POST
DC	0.55 ± .19	0.78 ± .36 *	0.72 ± .27
AC	0.43 ± .13	0.58 ± .14 *	0.56 ± .10
CON	0.49 ± .37	0.51 ± .23 *	0.57 ± .49
Mean or Peak Integrated Electromyography (measured in millivolts) ± Standard Deviation, DC= Direct Current, AC= Alternating Current, CON= Control, * Statistically Significant $p < .05$			

Figure 1: Rectus Femoris Mean Integrated Electromyography at 60 Degrees

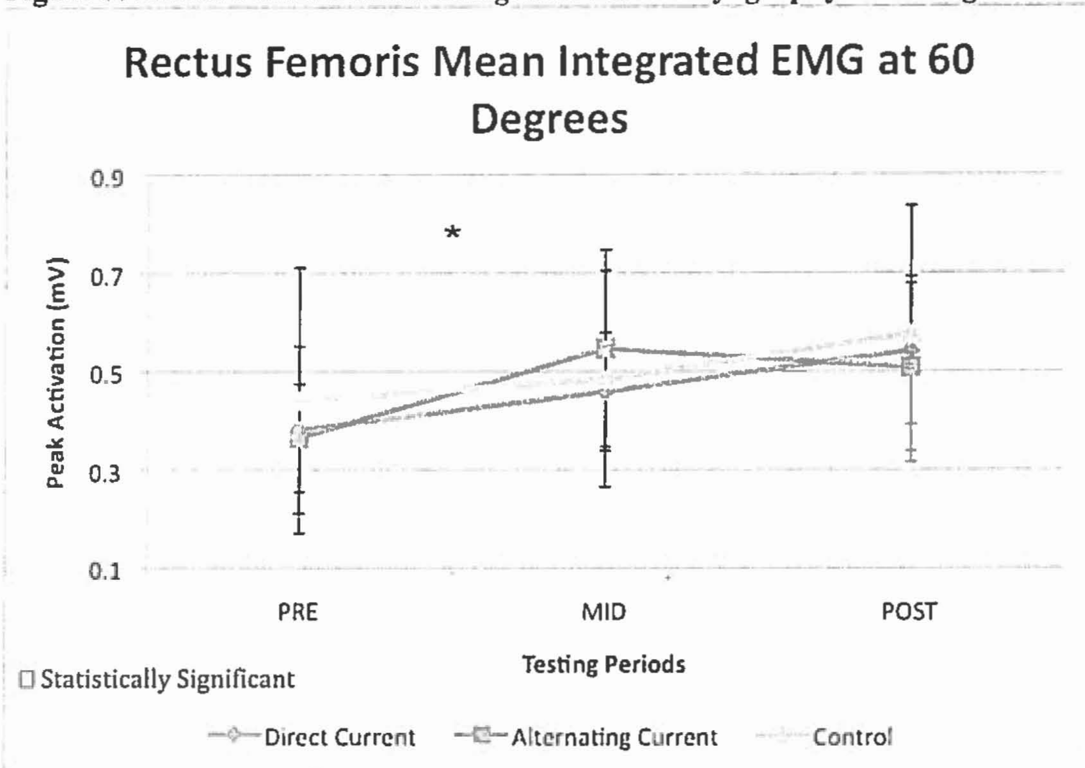


Figure 2: Rects Femoris Peak Integrated Electromyography at 60 Degrees

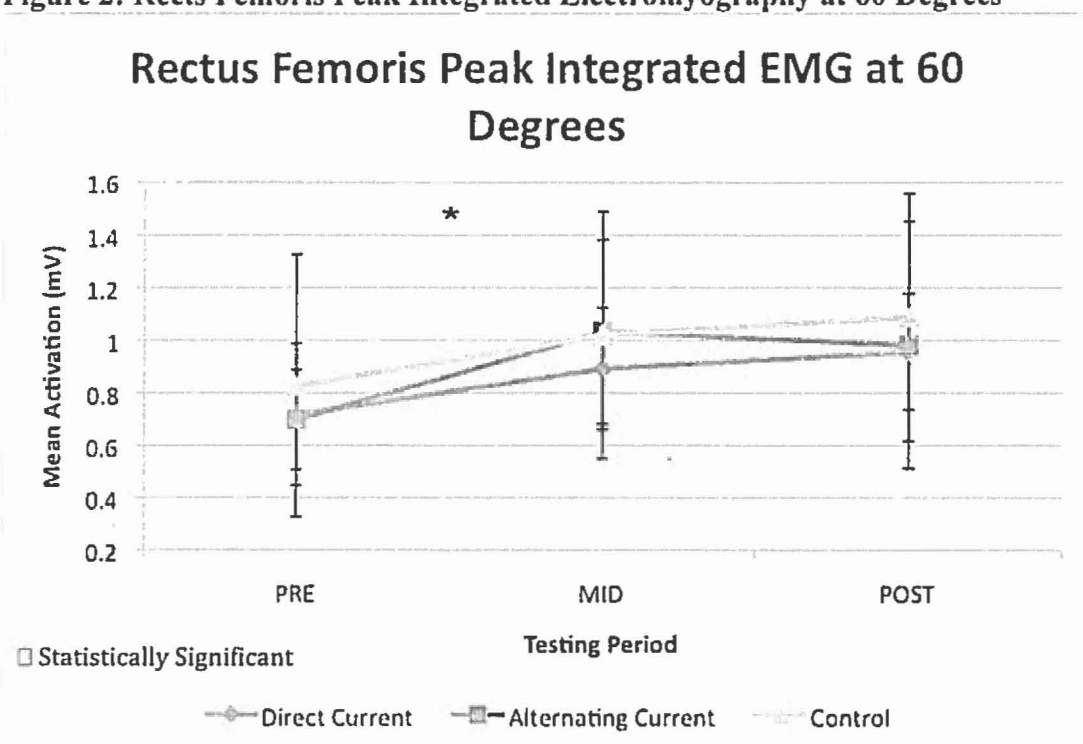


Figure 3: Vastus Lateralis Mean Integrated Electromyography at 60 Degrees

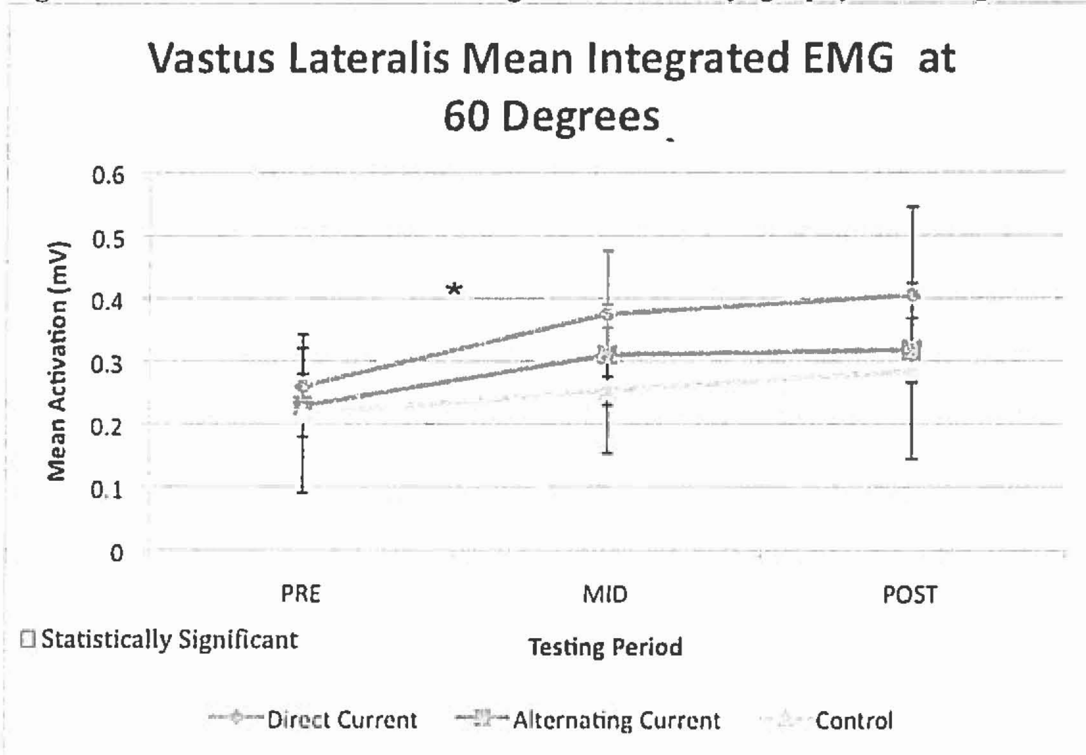


Figure 4: Vastus Lateralis Peak Integrated Electromyography at 60 Degrees

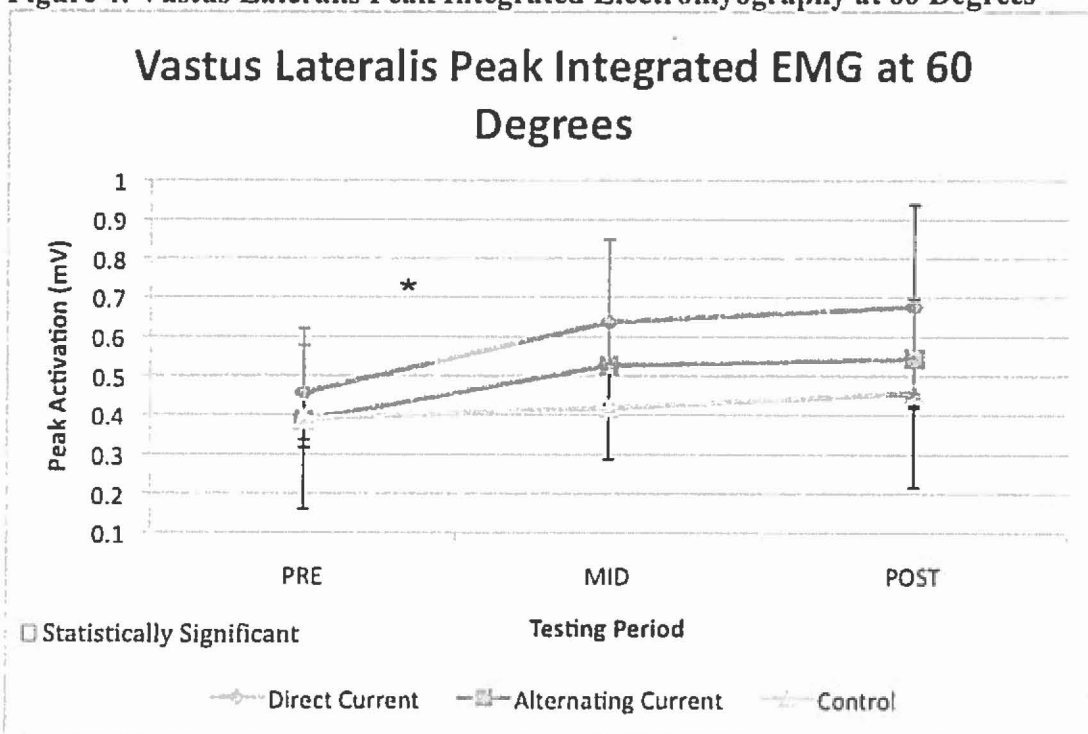


Figure 5: Vastus Medialis Mean Integrated Electromyography at 60 Degrees

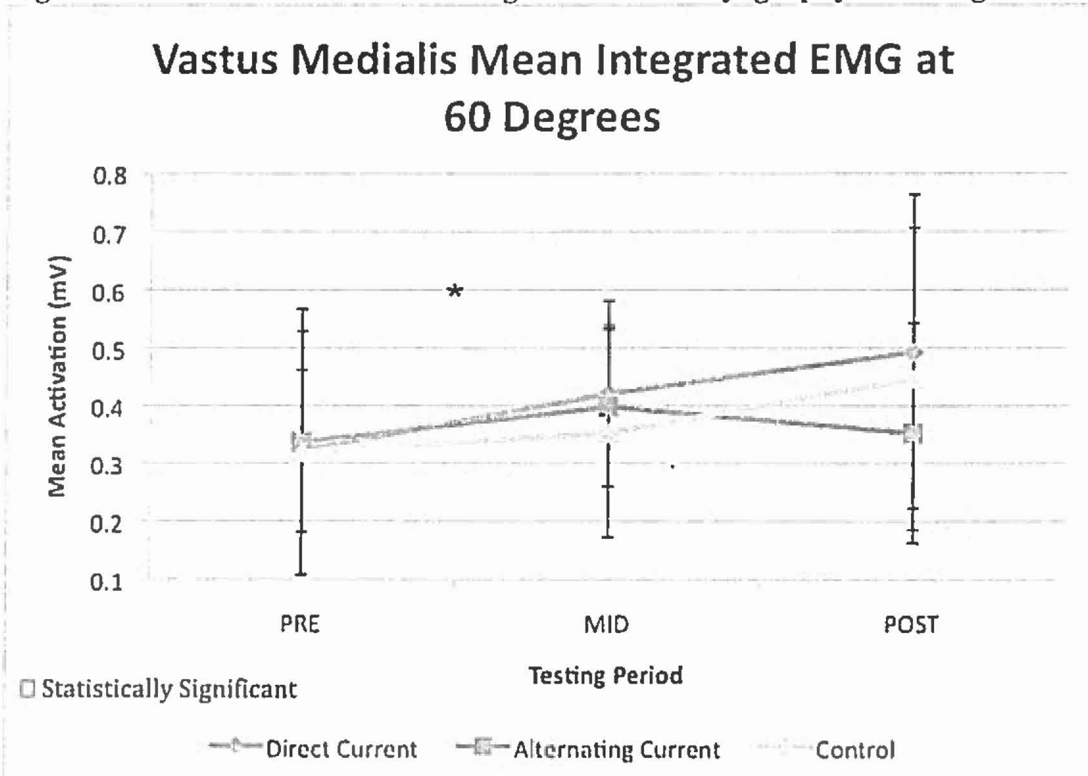


Figure 6: Vastus Medialis Peak Integrated Electromyography at 60 Degrees

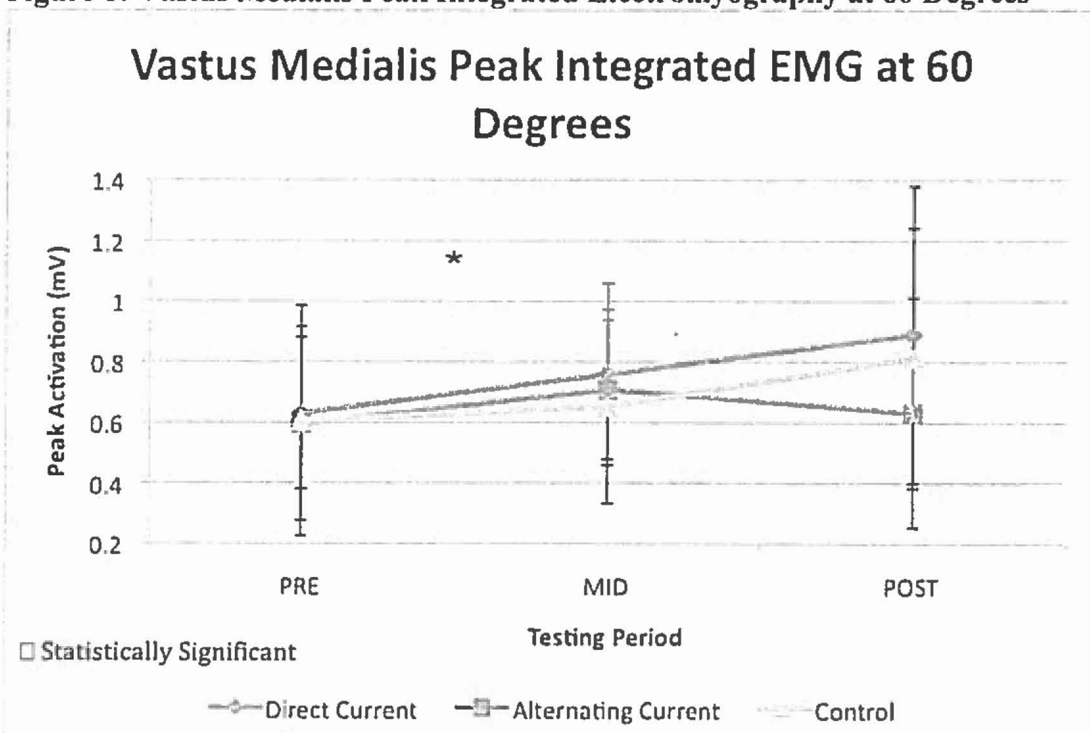


Figure 7: Vastus Lateralis Mean Integrated Electromyography at 90 Degrees

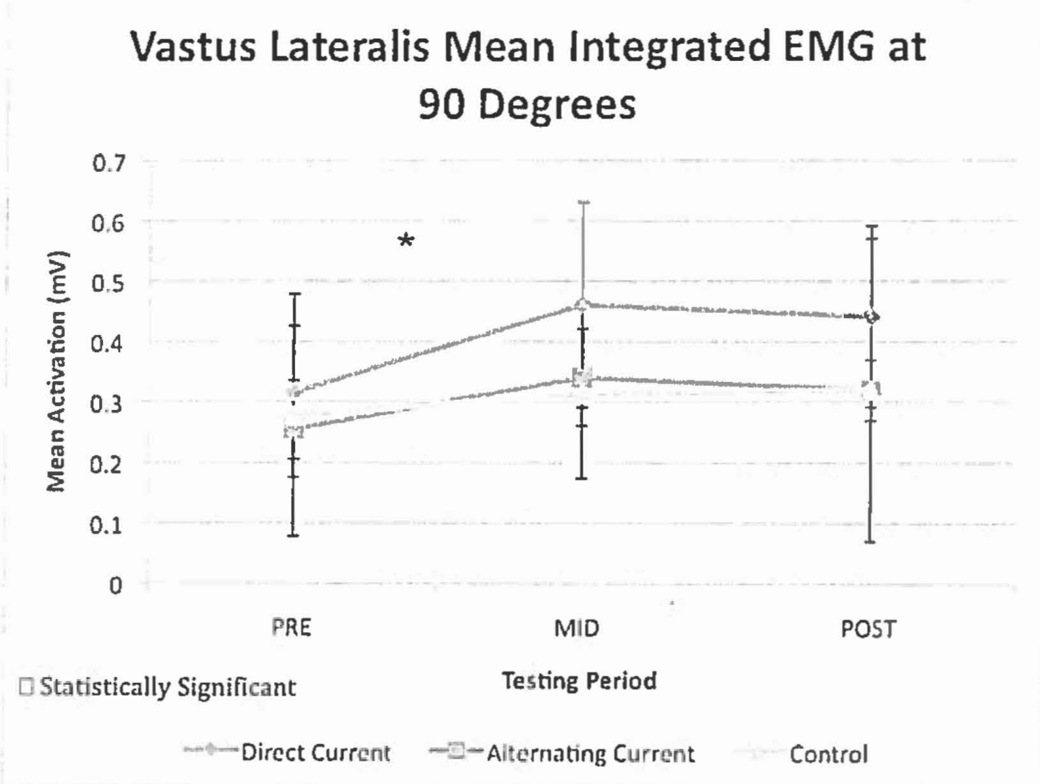


Figure 8: Vastus Lateralis Peak Integrated Electromyography at 90 Degrees

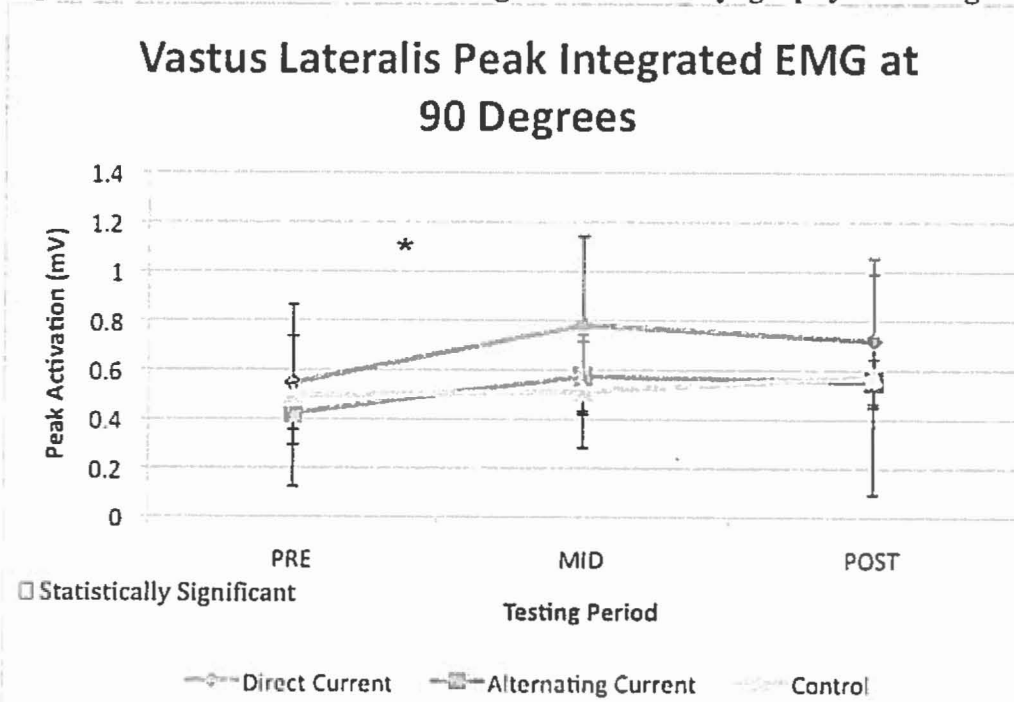
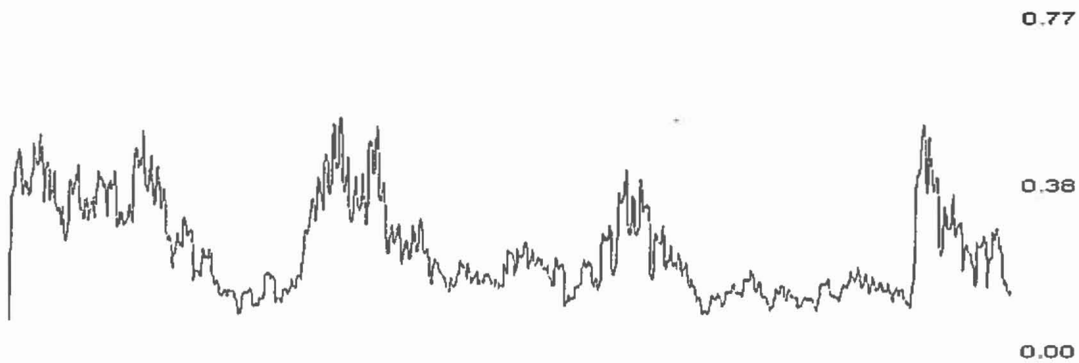


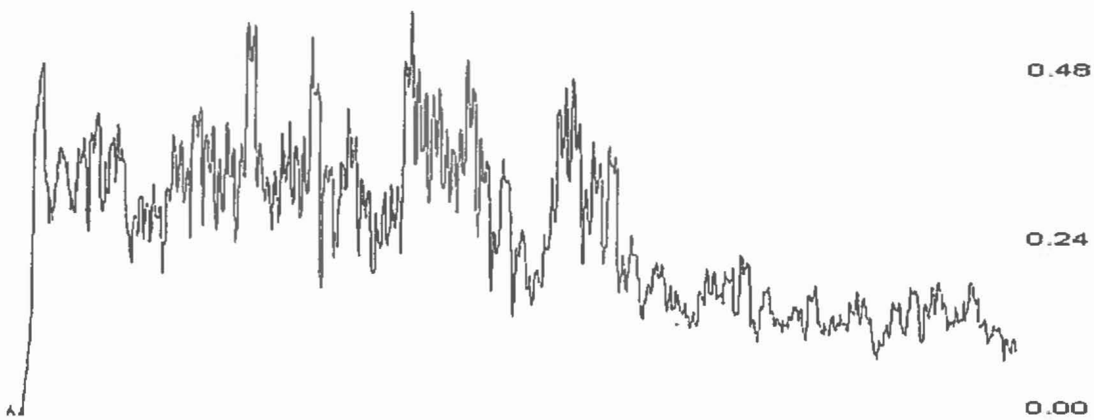
Figure 9 PRE Rectus Femoris Integrated Electromyography Signal at 60 Degrees

Participant 022 (Direct Current)

Mean .2037 mV Peak .522 mV



MID (3 Week)
Mean .2282 mV Peak .5659 mV



POST (6 Week)
Mean .4441 mV Peak .8819 mV

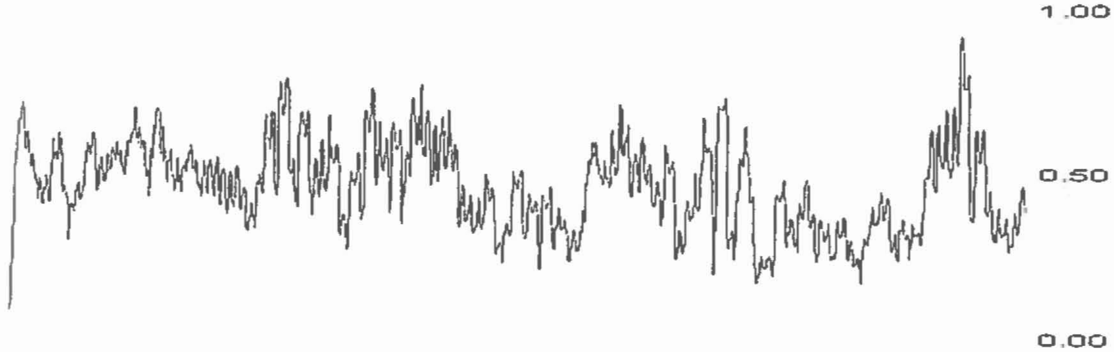
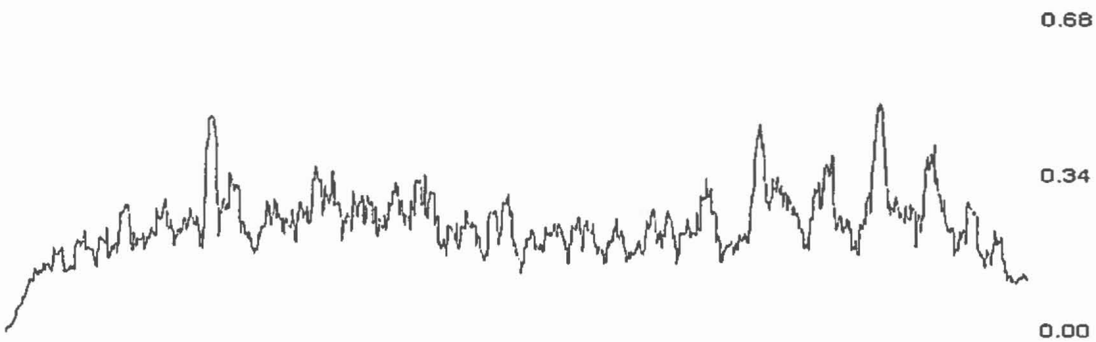
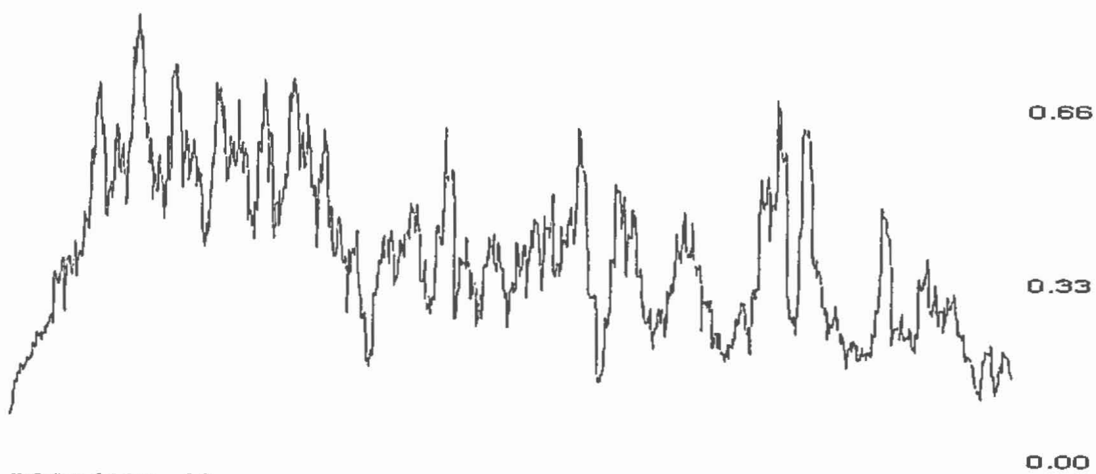


Figure 10: PRE Rectus Femoris Integrated Electromyography Signal at 60 Degrees Participant 029 (Alternating Current)
Mean .2715 mV Peak .6399 mV



MID (3 Week)
Mean .3541 mV Peak .8014 mV



POST (6 Week)
Mean .4432 mV Peak .8099 mV

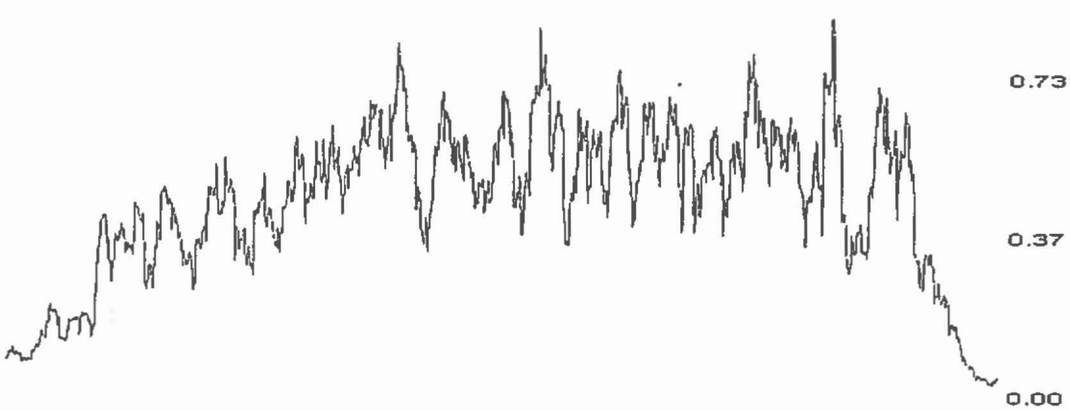
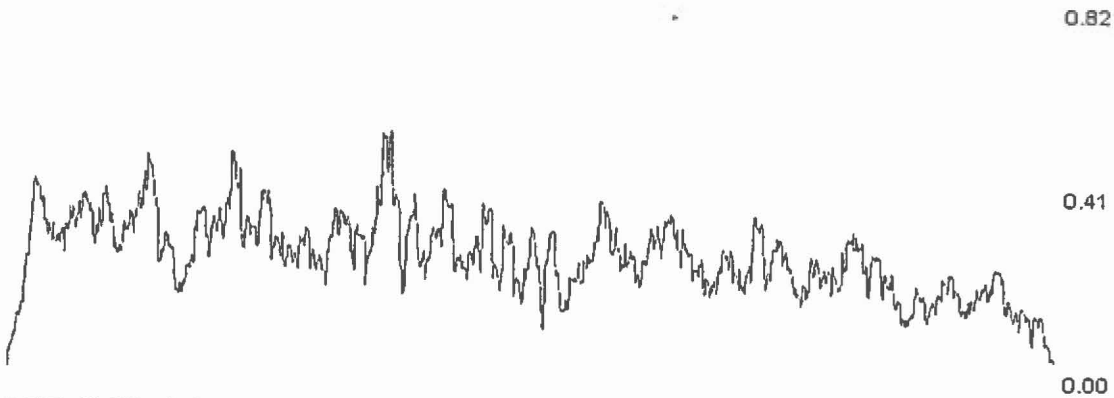
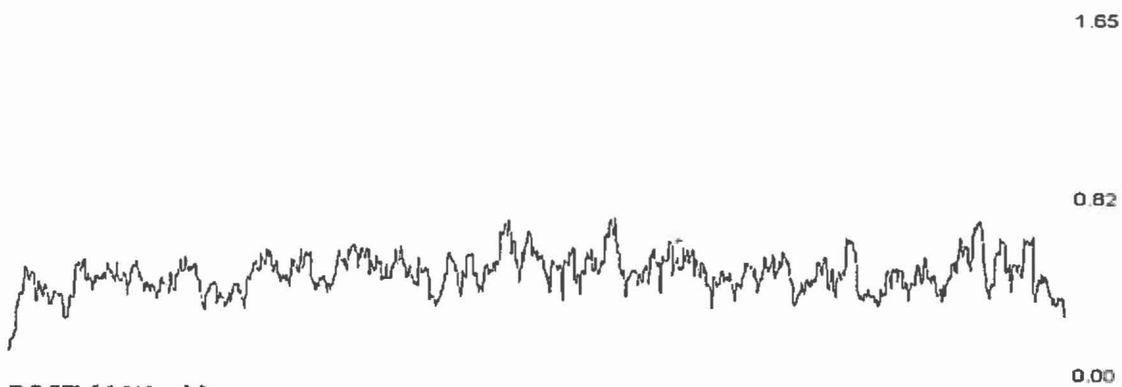


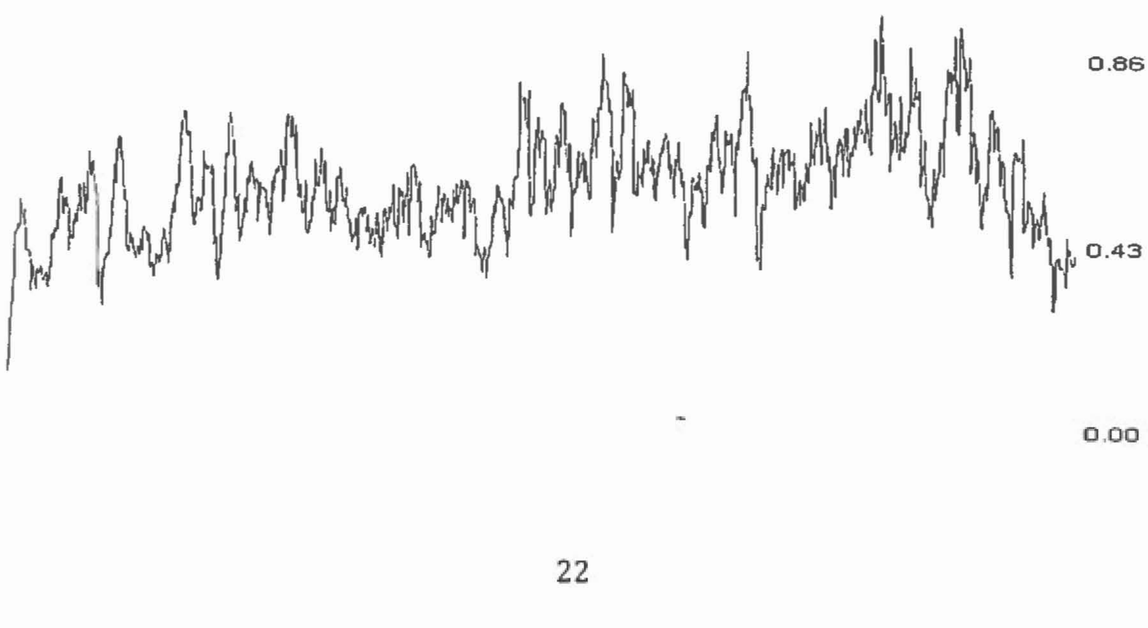
Figure 19: PRE Rectus Femoris Integrated Electromyography Signal at 60 Degrees Participant 032 (CON)
Mean .2911 mV Peak .5304 mV



MID (3 Weeks)
Mean .4244 Peak .7182



POST (6 Week)
Mean .5239 Peak .8736



Thigh Girth

Girth measurement data at all locations (at 5, 10, 15, and 20 cm above superior pole of patella) were not significantly different in the non-contracted or contracted positions of knee extension ($p > .05$) and are presented in Table 7. Additionally no significant differences were seen among data collection test periods between or among any of the measurement locations in the non-contracted or contracted positions of knee extension($p > .05$).

Table 7. Mean and Standard Deviation of Thigh Girth

Mean and Standard Deviation of Thigh Girth (cm)						
	5 cm			5 cm Contracted		
	PRE	MID	POST	PRE	MID	POST
DC	42.87 ± 3.82	42.84 ± 4.64	42.66 ± 3.83	42.66 ± 3.66	43.00 ± 3.72	42.73 ± 3.82
AC	44.71 ± 4.51	44.73 ± 4.12	44.49 ± 4.27	44.73 ± 4.61	44.98 ± 4.28	44.70 ± 4.19
CON	45.73 ± 5.47	46.58 ± 4.56	45.85 ± 4.53	46.15 ± 5.39	46.85 ± 4.75	46.16 ± 4.74
	10 cm			10 cm Contracted		
DC	47.86 ± 3.79	48.27 ± 4.09	47.69 ± 4.10	48.31 ± 3.68	48.22 ± 3.78	48.10 ± 3.97
AC	50.03 ± 5.13	49.95 ± 4.62	49.86 ± 4.69	50.30 ± 5.15	50.31 ± 4.86	50.12 ± 5.24
CON	51.04 ± 5.13	51.92 ± 4.23	51.09 ± 4.52	51.89 ± 4.46	51.99 ± 4.29	51.49 ± 4.42
	15 cm			15 cm CONTRACTED		
DC	52.33 ± 3.68	52.14 ± 4.00	52.15 ± 4.28	52.42 ± 3.67	52.24 ± 3.92	52.38 ± 4.00
AC	54.56 ± 5.21	54.35 ± 5.16	54.33 ± 4.95	54.38 ± 5.16	54.46 ± 5.27	54.43 ± 5.11
CON	55.68 ± 4.29	56.08 ± 3.84	55.49 ± 4.20	56.54 ± 4.52	56.40 ± 3.93	55.76 ± 4.26
	20 cm			20 cm CONTRACTED		
DC	55.39 ± 3.88	55.36 ± 4.34	55.31 ± 4.06	55.74 ± 3.94	55.52 ± 4.36	55.42 ± 4.02
AC	57.29 ± 5.21	57.12 ± 5.28	57.26 ± 4.91	57.37 ± 4.93	57.19 ± 5.35	57.45 ± 4.95
CON	59.36 ± 4.07	59.29 ± 4.18	59.06 ± 4.58	59.70 ± 4.02	59.59 ± 4.07	59.42 ± 4.70
Mean ± Standard Deviation, DC= Direct Current AC= Alternating Current, CON= Control, Yrs=Years cm=centimeters						

DISCUSSION

This was the first study to compare the effects of superimposed direct and alternating current on quadriceps femoris isometric torque production while training isometrically at 60 degrees of knee flexion for six weeks with a control group undergoing the same training regimen without stimulation. Repeated measures ANOVAs revealed that superimposed electrical stimulation did not increase changes in isometric strength significantly greater than controls at 60 degrees ($p=0.942$) or 90 degrees ($p=0.677$) of knee flexion. The lack of significant finding in this study are supported by previous research conducted on superimposed alternating current training with isometric contractions which indicate that results are equally as effective as training without electrical stimulation [15, 24]. Brazerra et al. also incorporated superimposed isometric knee extension training program within healthy participants and found no additional training effects with the trained leg [15]. Currier et al. studied superimposed training among asymptomatic individuals performing isometric knee extension and concluded that superimposed training is not any more effective when applied to healthy individuals [24]. However, Currier et al. speculated that atrophic muscle due to injury may be more responsive to superimposed training [24].

Repeated measures ANOVAs also revealed no significant difference between or among groups at 60 and 90 degrees for iEMG output or thigh girth at 5, 10, 15, and 20 cm in the non-contracted and contracted states over the six-week isometric training period. Thus the hypothesis that isometric torque training superimposed with direct or alternating current will elicit greater motor unit recruitment and muscle hypertrophy resulting in increased torque production when compared to controls was rejected.

Significant main effects for data collection periods were observed for both MVIC and iEMG, indicating that strength significantly improved regardless of condition. The effectiveness of superimposed training for improving muscular strength in previous studies has been inconclusive [11-18]. A direct comparison of studies was difficult due to discrepancies of training protocols and methodology. A variety of parameters have been implemented with superimposed training in the previous literature, including: types of contractions (isotonic, isometric and isokinetic), neuromuscular electrical stimulation currents, training load, or training experience [11, 12, 18, 25, 26]. It has been speculated that increasing stimulation duration induces greater neuromuscular stimulus resulting in more notable developments in muscular strength [25]. Willoughby and Simpson increased training load via superimposing AC current during both concentric and eccentric phases of the isotonic exercise [11, 12]. They reported that muscular strength training by superimposed contraction resulted in a greater 1-RM and vertical jump height than that resulting from non-electrically stimulated training. The authors concluded that superimposed training was a better method in strength training than resistive weight training alone.

Wolf et al. incorporated direct current superimposed training in asymptomatic trained individuals and reported that training without electrical stimulation superimposed training. Although non-significant, they reported that improvement in muscular strength was greater among participants in the superimposed group compared to the control group. [18] It should be noted that results of that study were obtained with participants performing a superimposed isokinetic squat. In the present study, muscular activation within superimposed groups was not significantly different from the CON group after the training period. This indicated that the healthy intermediately trained participants were able to effectively activate their quadriceps femoris to the extent that no further benefit was gained with the application of NMES. However, close examination of the figures show the possibility of improved performance due to superimposed direct current. Both the Vastus lateralis and the vastus medialis at 60 degrees of knee flexion demonstrated greater motor unit recruitment in response to direct current stimulation. The vastus lateralis showed a greater response to direct current training when assessed at 90 degrees of knee flexion.

Quadriceps strength in the superimposed groups resulted in improvements 30 degrees beyond training angle (60 degrees of knee flexion). Previous researchers have studied the effects of isometric training on strength and have reported greater gains with the angle associated with training [27, 28]. Typically improvements in isometric strength have been proven to carry over within plus or minus 20 degrees of the training angle [29]. Thus, improvement in peak torque at 90 degrees, as seen in the present study, may indicate isometric training with NMES increases strength at an angle greater than 20 degree on either side of the training position. Bandy et al. [30] reported the degree of the carry over effect in isometric training is contingent on the length of muscle upon exercise. In the present study, greater carry over effect was demonstrated with the quadriceps femoris in a lengthened position, despite training in a shortened position, probably due to the position of the cross bridges and length tension optimization. Despite the possible trend towards a carryover effect, superimposed training was not more effective than voluntary isometric training in increasing muscular torque.

Hartsell [31] demonstrated increases in thigh girth with untrained individuals subjected to superimposed alternating current stimulation. Although gains in that study were observed with the superimposed group, it should be noted that results were achieved with the group that started with lowest pre-training values. In an unpublished pilot study conducted by Richardson et al. [32], the same direct current stimulator used in the current study was incorporated in post-surgical anterior-cruciate ligament patients rehabilitation protocol and a 300 percent increase in thigh girth was reported after two months of training. Isometric exercise is an important therapeutic component when recovering from injury as it does not stress the joint structures as much as isotonic or isokinetic exercise. Therefore isometric exercise is usually the first type of exercise prescribed post surgically.

In contrast to Hartsell (26), muscular hypertrophy assessed by thigh girth did not appear to contribute to the improvements in strength in the present study, which may be due to the use of intermediately trained participants. The results of the current study were similar to those reported by Currier and Mann [33], who also used superimposed alternating current with isometric knee extensions and reported quadriceps muscular hypertrophy was not evident after five weeks of training.

Several limitations need to be acknowledged in the present study. The first limitation was that an appropriate sample size was not obtained. An *a priori* power analysis was conducted with a power of .8 and an alpha level of $p < .05$. The calculation was performed with a moderate to small effect size based on Cohen at 0.25. According to analyses, the current study required a sample size of at least 36 or 12 per a group. Consequently, this study had low power with only 10 subjects per group. The second limitation concerns assessment of muscular hypertrophy. Utilization of thigh girth measurement may not accurately portray changes in muscular size because of the inability to differentiate between adipose and muscle tissue [34]. Researchers advocate computerized tomography, ultra-sound, dual energy X-ray absorptiometry, and magnetic resonance imaging as these methods allow for a more thorough examination of muscular changes [34, 35]. Thirdly, training and testing time were not always consistent due to conflicting participant schedules, which could have been affected by ones circadian rhythm. Sedliak et al. [36] reported time of day, has an influence on isometric muscular strength performance due to the fluctuation of diurnal pattern.

In summary, no additional benefit in muscular strength resulted from six weeks of superimposed quadriceps isometric training when compared to isometric training. Participants might have been able to optimally activate the quadriceps femoris via voluntary contraction, thus no additive effect resulted from superimposition. No changes were demonstrated in thigh girth indicating muscular strength improvements were more likely due to neuromuscular adaption, rather than muscular hypertrophy. Additionally, the carryover effect for isometric training was greater in the present study than has been previously reported. It was concluded that within the limitations of the present study neither superimposed direct or alternating current significantly increased isometric strength beyond what was achieved by isometric training alone.

Practical Applications

There is no additional benefit to isometric strength training with electrical stimulation in healthy intermediately trained participants. Nonetheless, superimposition of electrical stimulus may benefit muscular strengthening in rehabilitation, as open chain exercises are a contraindication with post-surgical ACL patients [37]. Often isometric exercises are implemented in the initial phases of rehabilitation to address muscular strengthening. Superimposed training may potentially increase the effects of isometric training by influencing more of the available range of motion, thus facilitating the strengthening component of rehabilitation.

REVIEW OF LITERATURE

Neuromuscular Electrical Stimulation (NMES) Overview

Several authors have speculated that MVC do not involve complete motor unit recruitment and that injury, age, and training level affect motor unit recruitment [8, 10]. Consequently, NMES has been utilized on injured and uninjured subjects to facilitate increases in motor unit recruitment with subsequent muscular strength gains. Previous research involving alternating and direct current NMES is limited and inconclusive [4-9].

Theoretically when NMES is applied concurrently to specific muscles involved in training regimens increases in motor unit recruitment results in increases in muscular torque production and is currently called superimposed muscular training [11, 12]. The additive effect of alternating NMES and strength training regimens has been shown to increase torque production greater than training regimens alone. Unfortunately, only one study included direct current [18].

Isometric Contractions

Isometric contractions are commonly prescribed in the rehabilitative setting following acute injuries and/or circumstances that involve joint injuries where range of motion is contraindicated. Previous literature indicates that isometric training is specific and limited to training angle. Lindh [28] studied the effects of isometric strength training on quadriceps femoris in ten healthy females (mean age 26.5 yr). Participants performed isometric knee extensions on a Cybex II dynamometer set at 15° of knee flexion with one leg and 60° with the other leg. The training regimen consisted of three sets of ten repetitions. Each repetition was held for six seconds with six seconds of rest between each repetition and two minutes between each set. Participants trained three days a week with an average of 15 training sessions completed. Maximum isometric contraction testing was performed at 15° and 60° of knee flexion. Additionally, isokinetic testing was performed at 30 deg/sec and 180 deg/sec. A Wilcoxon's test was used for statistical analyses. Results indicated significantly greater gains in strength at the trained angle (Angular Specificity). Improvement was reported with lower isokinetic testing velocities (30 deg/sec), but not at higher testing velocities. Lindh theorized improvements in low dynamic strength (30 deg/sec) were a result of the relative similarities with isometric contractions compared to high dynamic strength testing (180 deg/sec).

Kitai and Sale [27], applied isometric training in an ankle strengthening program and their results revealed angular specificity. The study included six women (mean age 21.8 ± .4 years old) who trained three days a week for six weeks with the ankle in the neutral position (90°). Training load per session consisted of two sets of ten contractions with each maximal contraction held for five seconds with two minutes of rest between sets. In regards to testing, isometric plantar flexion and dorsi-flexion at 5°, 10°, 15°, 20° were evaluated. Furthermore, researchers assessed muscular activation through the method of twitch-interpolation described as an electrical stimulus delivered during maximal isometric contraction. A change in torque subsequent to stimulus represented deficiency in muscular activation. A 2-factor ANOVA was used for statistical analysis. Tukey's post-hoc test followed if results were significant ($p \leq .05$). Application of twitch-interpolation demonstrated no significant changes at any angle, indicating neural adaptation was responsible for training response.

Consequently, Bandy and Hanton [30] reported greater improvements in knee extension torque across a joint range of motion with the muscle at a lengthened state during isometric training. Study involved 117 untrained healthy females (mean age 23.8 years old). Participants were divided into 4 groups that trained at different angles (Control group, 30°, 60°, and 90° of knee flexion). Isometric knee extension was performed 3 times a week for 8 weeks. In each session, participants performed 20 contractions held for 6-seconds. Upon completing training, isometric testing was conducted at 15° increments from 15-105° of knee flexion. In addition to strength testing, electromyographic data was also collected and used to assess muscular activation. A two-way multi-variate analysis of variance for repeated measures was performed for statistical analyses. Tukey's test was used for post-hoc analysis if significance was found. Authors reported improvements in strength through out a joint range of motion were also accompanied by an increase neuromuscular activation.

Thepaut-Mathieu et al. [38] noted improvements in maximum voluntary contraction throughout a joint angle, although strength gains were always greater at the angle trained. Researchers also mentioned strength improvement amongst a joint range of motion was limited by muscle length. The researchers studied 8 male participants performing isometric bicep curls 3 days a week over a course of 5-weeks. Participants were divided into groups: shortened 120° (S), medium 80° (M), lengthened 25° (L), and control (C). Degrees of groups were representative of elbow joint positioning and related to length of biceps during exercise. Training sessions were comprised of 5 repetitions at 5 sets (80% of 1 repetition max). Strength testing and EMG was collected at 25°, 50°, 80°, 100°, and 120° of elbow flexion. A test of variance was used for statistical analysis. McNemar's

Test was specifically incorporated for EMG data. Significance level was set at .05. In agreement with Bandy and Hanton, EMG data was consistent with an increase in muscular activation. Aside from angular specificity, previous researchers have reported and acknowledged the effectiveness of isometric training within the biceps brachii, quadriceps femoris, and triceps surae.

In regards to neuromuscular adaptations associated with isometric training, Moritani [39] investigated 15 healthy participants (8 females mean age 18.2 years old and 7 males mean age 22 years old) in a 8-week training period. Testing composed of isometric strength and electromyography was performed every 2 weeks. For training, participants performed isometric bicep curls with elbow at 90 degrees of flexion 2 times a day 3 days a week. Exercise consisted of 10 repetitions with a load equal to 2/3 of 1-repition max. A T-test was carried out for a statistical analysis. Results indicated strength gains experienced early in training are mainly a result of neurological adaptations. As the training progressed, muscular hypertrophy emerged as the primary contributor in strength improvements.

An alternative method of voluntary isometric strength training involves electrical stimulation to stimulate muscular tissue and result in an isometric muscular contraction. The application of an electrical current to cause a muscular contraction is referred to as neuromuscular electrical stimulation.

Neural Adaptations with NMES

Maffiuletti NA, Pensini M, and Martin A [40] reported an 11.9% increase in plantar flexor (Soleus, medial and lateral gastrocnemius) activation after a four week, four sessions per week isometric NMES training with eight healthy males (mean age 20.4 ±2.1 yrs). During each session 45 isometric contractions were performed. Analysis of variance with repeated measures was used to determine the effect of NMES training. Results indicated significant increases in muscular torque output at isokinetic velocities of -60°/sec and -120°/sec eccentrically; and no significant differences in concentric isokinetic modes. Increases in strength were accompanied by 1) greater EMG activity of agonist, but not with the antagonist enhanced maximum voluntary activation 3) and augmented post activation potentiation. The authors theorized that the 11.9% increase in post activation potentiation was due to activation of larger motor units. The results suggested that increases in muscular activation may have been the result of an increase in volitional drive from the supraspinal centers.

Gondin J, Guette M, Ballay Y, and Martin A [2] reported increases in neural drive of the quadriceps femoris. Twenty untrained males (mean age: 23.5 ± 5.0 yrs) performed 40 electrically stimulated isometric contractions four times a week for eight weeks for a total of 32 sessions. A portable battery powered device with a rectangular wave pulse current of 400 microseconds was used for superimposed stimulation. Electromyography was collected and amplified by a bandwidth filter ranging from 5Hz to 15Hz (common mode of rejection = 90 dB, impedance = 100 MΩ, Gain = 1000). A two-factor ANOVA with repeated measures was used to compare the dependent variables. Quadriceps

Femoris maximum voluntary isometric contractions increased 27% and quadriceps activation increased 6% (twitch interpolation method). Vastus lateralis and vastus medialis muscle activation significantly increased 69% and 39%, respectively. No significant differences were revealed in the rectus femoris. Authors noted that neuromuscular adaptations were more prevalent in first four weeks and muscular architectural changes were observed between weeks four through eight.

Trimble and Enoka [41] studied the relationship of H-reflex and and M-response in 22 (15 male, 7 female, ranging in age 19 to 53 yrs) healthy participants. H-reflexes represents a summation of motor units (voluntary contractions), variation in time to peak twitch indicates preferential larger motor unit recruitment. M-response involves stimulus delivered to efferent axons and involves selective recruitment of faster motor units. To obtain an H-reflex, electrical stimulation electrodes were placed directly over the muscle belly quadriceps femoris (femoral nerve) and gastrocnemius (posterior tibial nerve). Researchers compared EMG latency, time to peak torque, and peak amplitude of electromyography potentials. A one-factor ANOVA with repeated measures was used to analyze the dependent variables. Researchers report time to peak torque increased with the M-response, suggesting that recruitment of slow motor units. Comparatively, a decrease in time to peak torque was demonstrated with the H-reflex. They concluded that NMES produces recruitment different from voluntary contractions by preferentially recruiting fast-twitch type II motor units.

Sinacore DR, Delitto A, King DS, and Rose SJ [42] investigated fiber type recruitment through a series of muscle biopsies. One healthy male participant (31 yrs) was use in the study. Quadriceps femoris maximum voluntary isometric torque was measured on Cybex® II isokinetic dynamometer at 60° of knee flexion. The subject endured a two hour exhaustive bike ride (80-90% of VO_2 Max) and then returned after three days of carbohydrate rich dieting for an electrical stimulation session. Plasma glucose and lactate concentration were collected pre-stimulation, at 1-minute intervals during stimulation, and at two-minute intervals for 15 minutes after stimulation. Stimulation was provided by 2,500Hz sinusoidal carrier wave with interruptions of 50Hz. Immediately after stimulation a muscle biopsy was taken from vastus lateralis. Samples were stained and after hydrolysis of muscle glycogen, the glucose units were analyzed by the flurometric method. Results indicated that glycogen depletion was more notable in Type IIa motor units, thus concluding electrical stimulation preferentially recruits. Type IIa motor units. This finding is not consistent with the idea of the reversal of size principle. Type IIa fibers are believed to have a greater oxidative capacity and would be recruited after Type IIb within the reversal of size principle.

Knaflitz M, Merletti R, and De Luca CJ [43] investigated motor unit recruitment patterns of voluntary contractions and electrically stimulated the tibialis anterior of 17 male and 5 female (mean age 29 ± 6.9 yrs) participants. The study incorporated conduction velocity (CV) as a variable representative of motor unit recruitment within the tibialis anterior. A monopolar technique was used with negative electrode placed on tibialis anterior and positive electrode placed on belly of gastrocnemius stimulated at 20, 25, 30, 35, and 40Hz. Two levels of stimulation were utilized, high (HLS, 10% above MVC) and low (LLS, 25-30% below MVC). Myoelectric signals were detected with a four bar sensor setup and processed with a low-pass filter and cut –off frequency of 480Hz. A non-parametric test was used for statistical analysis. At HLS force range from

7.5 and 38% (Average 26.5 ± 4.6%). Electromyography on the premise of Median Frequency (MDF) and Mean Frequency (MNF) were positively correlated with muscular activation level. Mean frequency and CV at 80% of MVC was greater than 20% of MVC. As for electrically stimulated muscles, CV increased as pulse rated increased. Not all cases presented with this trend, a negative correlation with CV and pulse rate was also reported. Researchers explained the phenomenon with fatigue from the stimulation protocol. One important point researchers mentioned was CV correlated with muscular activation tended to be greater in MVC compared electrical stimulation.

Restoring Neuromuscular Function in Post-Surgical ACL Patients

Snyder-Mackler L, Delitto A, Stralka SW, and Bailey SL [5] investigated the dosage or "training intensity" NMES had on post-surgical ACL patients. This study involved training contraction force of the elicited muscle by electrical stimulation. Subjects were 52 (40 male and 12 female, mean= 25 yrs) out of a population of 110. Electrical stimulation training began two weeks post-surgery. Two types of stimulators were investigated, a clinical grade (Versastim 380; 2,500 Hz triangular alternating current at burst rate of 75 Hz) and portable stimulator (pulse duration 300 microseconds, frequency cycle 55 Hz, on/off time 15/50 seconds). Treatment of the clinical stimulator group involved 15 electrically elicited isometric contractions at 65° degrees of knee flexion against an immovable dynamometer arm (isometric). Treatment for the portable stimulator differed and consisted of 15 minutes, four times a day, five days a week. Participants who utilized the portable stimulator performed an exercise that required them to stabilize their knee at 90° of flexion with a theraband. A Pearson Product Moment

Correlation Coefficients and regression analysis were used to evaluate the relationship between dosage and current intensity. The results of the study indicated that higher current intensity resulted in quicker quadriceps femoris muscle recovery. The authors concluded that use of the portable stimulator did not increase quadriceps femoris recovery as much as the clinical grade stimulator.

Delitto A and Snyder-Mackler L [44] examined 20 patients (unspecified gender, mean age 29 yrs) with anterior cruciate ligament tears who and had undergone reconstructive surgery. Participants were placed in either an electrical stimulation group (n=10) or voluntary exercise group (n=10). The electrical stimulation group was treated five times a week for three weeks. Stimulation was delivered to quadriceps femoris and hamstrings muscles in a co-contracting manner. Current was characterized as a sawtooth waveform, 2,500 carrier wave, and 50 pulses per second. Co-contractions were 15-seconds in duration with a 50-second rest period. The voluntary exercise group performed the same training protocol with the exception of voluntary muscle contraction only. After the treatment period, maximal isometric knee extension and flexion were measured at 65° of knee flexion. Independent t-tests were used to analyze differences in knee extension and flexion torque between electrical stimulation and voluntary exercise groups. A Bonferroni correction factor was applied to adjustments of the Alpha level (multiple t-tests). Results of study indicated greater isometric strength gains in the electrical stimulation group than in the voluntary exercise group.

Snyder-Mackler L, Ladin Z, Schepsis AA, and Young JC (64) indicated that NMES with different types of stimulators were effective in re-educating muscular tissue, with one stimulator more effective than the other. Limitations of Delitto et al. study involved the voluntary exercise group; participants were instructed to contract as "hard" as they could with no indicator or gauge to assess the subjective term ("hard"). The authors suggested using biofeedback to improve their study. Training between the stimulation group and voluntary exercise group differed as the electrical stimulation group performed a co-contraction of quadriceps femoris and hamstrings while the voluntary exercise group exercised each muscle independently. Neuromuscular electrical stimulation is an accepted method of restoring neuromuscular function and resolving muscular inhibition caused by injury. Neuromuscular inhibition is not only apparent with post-surgical ACL patients, but also with non-injured healthy individuals.

Muscular Inhibition in Non-injured Individuals

Huber A, Suter E, and Herzog W. [8] assessed muscular inhibition in 13 elite male (23.5 ± 2.3 yrs) volleyball players. Subjects completed a medical history questionnaire. The questionnaire revealed history of injuries (8 patellar tendonitis, 1 bursitis, and 1 partial tear of patellar tendon), which was used for group assignment (group by leg: uninjured 11, previous injury 7, and present injury 8). Authors utilized the twitch-interpolated technique (discussed below) to quantify and estimate quadriceps femoris inhibition. Stimulation was characterized as a single square-wave pulse of 240 V and .8 microsecond duration. Participants were given three attempts to perform maximum voluntary isometric knee extension at 30° and 60° (0°=full extension). Throughout testing, a visual analog pain scale was used to assess discomfort and pain from the electrical stimulation. Non-parametric tests were used to assess group differences. No significant differences in knee extensor moments were reported between three groups.

The greatest amount of inhibition was demonstrated with participants in the non-injury group while the injured knee group showed the least amount of inhibition. Moderate pain during testing resulted in reduced knee extension moments.

Results of Huber et al. study conflicted with researchers' hypothesis, that greater muscular inhibition would be demonstrated with injũred subjects. The authors theorized that intense rehabilitation of injuries re-establishes and compensates for reduced activation resulting in less inhibition. As revealed with the aforementioned study, neuromuscular inhibition can also exists within healthy individuals. Twitch interpolation has been a purposed method for assessment of muscular inhibition. Twitch interpolation is a technique utilized during a maximum voluntary contraction (most often isometric) to assess muscular inhibition. The technique involves eliciting an electrical pulse or a train of pulses during a maximum voluntary contraction. Theoretically deficiency is present if additional torque is generated by the electrical stimulus. If no additional torque is generated via an electrical stimulus, maximum voluntary contraction and complete muscular activation is assumed.

Assessing Muscular Inhibition

Herbert and Gandevia [45] investigated muscular activation by twitch interpolation technique in three healthy subjects ages ranging from 29-44 years old. Twitch interpolation technique was applied to the ulnar nerve to stimulate adductor pollicis muscle at following order of stimulation frequencies trains: 1, 5, 10, 20, 50, 100, 100, 50, 20, 10, 5, and 1 Hz. Researchers noted that at 100 Hz an average of 60.3% of maximal voluntary force was attained. Of particular interest was excitation threshold level; motor neurons firing frequency increased as excitation increased. Results revealed that interpolated twitch decreased as voluntary contraction increased. Furthermore, amplitude of stimulated interpolated twitches seemed to overestimate activation levels (12% for resting twitch). Time-to-peak force was longer in the twitch interpolated technique than maximum voluntary contraction (26 ms compared to 19 ms). During stimulated maximum voluntary contractions an 8.7% increase in twitch was demonstrated without antidromic collisions (neural conduction travel in the opposite direction of normal conduction) and 4.7% increase with collisions. Results indicate that antidromic collisions decreases peak twitch. Researchers also concluded that at forces greater than 90% of maximum voluntary contractions, the interpolated technique is not a sensitive tool for assessing muscular activation.

Miller M, Downham D, and Lexell J. [46] studied the central activation failure or suboptimal motor unit recruitment of 24 healthy males (mean 25.8 ± 3.5 yrs) via twitch interpolation. In particular the researchers looked into parameters of NMES to optimize twitch interpolation technique by minimizing pain potentially caused by the stimulation. Electrical stimulation was applied to the quadriceps femoris with the proximal electrode placed on the motor point of the rectus femoris and distal electrode placed seven cm proximal to the patella. For twitch-interpolated test, subjects contracted at 80% of maximum voluntary contraction in addition of electrical stimulus. Subjects were asked to rate their discomfort level on visual analog scale for pain. The study consisted of two parts with the first part including two different sets of electrical stimuli delivered 1) 50 ms pulse train and 2) 100 ms pulse train. The second part of experiment consisted of eliciting eight electrical pulse trains of 100 ms with a frequency of 100Hz. Four of the eight pulses consisted of .1 ms phase duration and another four contractions with a .2 ms phase duration. Multi-variate analysis of variance was used to analyze the results. Results of this first part of the experiment indicated that a 100 ms pulse train increased torque greater than a 50 ms pulse train, although more discomfort was experienced with a 100 ms pulse train. The second part of the experiment indicated that a .2 ms pulse duration generated torque levels similar to a .1 ms phase durations. Pulse trains with a .2 ms phase duration correlated with higher pain scores (4.8 mm higher) than .1 ms phase duration.

The extent of muscular inhibition is one of the components that determine the efficacy of NMES strength training. Parameters of NMES current also influence motor unit recruitment and response to training. Stimulation current must be sufficient enough to impose a stress that recruits motor units without causing discomfort and results in increases in muscular torque.

NMES Parameters

Rooney JG, Currier DP, and Nitz AJ. [47] investigated the effects of different combinations of burst (50, 70, 90 burst per second) and carrier frequencies (2,500, 5,000, and 10,000 Hz) on stimulation discomfort of 27 healthy subjects (22 males and 5 females). Maximum voluntary isometric knee extension was measured on a Cybex II Isokinetic Dynamometer. A visual analog scale was used to assess the perceived discomfort experienced with stimulation current. An ANOVA for repeated measures was used to analyze peak torque and visual analog scale. Within all the combinations of burst frequencies and carrier frequencies, the 10,000 Hz carrier frequency combined with the three bursts per second only caused discomfort. Authors reported a 10,000 Hz carrier frequency did not seem to cause a tetanic appearing contraction. A plausible explanation for this was that the current or phase charge was not effective enough to stimulate additional motor units.

Ward AR and Robertson VJ. [48] investigated the effects AC frequency on muscular torque production in 12 healthy subjects (7 males and 5 females, 31-48 yrs, mean age 42). Neuromuscular electrical stimulation was applied to extensor digitorum. Implementation of alternating currents ranging form 1 and 15kHz, modulated at 50Hz. The study was divided into two parts. The first part of the study consisted of applying six frequencies individually: 1, 2, 4, 7, 10, and 15kHz. Subjects were asked to increase stimulation intensity to a point of where they felt the stimulation. After obtaining a point at which stimulation was felt, they were asked to increase stimulation intensity to a point of muscular contraction. Maximum intensity without pain was established when criteria of stimulation intensity was high enough to tolerate for 10 seconds. Part two of this study involved 1, 4, and 10 kHz used to evaluate isometric muscular torque output. All subjects were involved the first part and only three subjects were included in the second part of the study. Testing involved a device that tested maximum voluntary isometric wrist extension. Results indicated that stimulation perception of 10k Hz was the better choice and muscular torque output was best demonstrated with 1 kHz.

Bennie SD, Petrofsky JS, Nisperos J, Tsurudome M, and Laymon M. [49] considered three important factors that influenced effectiveness of NMES: mean stimulation current, comfort, and physiological response. Subjects were four male and three female subjects (age range 20-60 yrs, mean age 33.1). Four types of NMES currents (square waveform, sine waveform, Russian, and interferential) were studied. Isometric knee strength was measured at 90 degrees by a device with a strain gauge attached to a steel bar. Intensity of stimulation device was adjusted to produce and maintain a muscular contraction 10% of MVC. Only two minutes of the four-minute contractions were stimulated. A 48-hour rest period was implemented between the two days of data collection to avoid fatigue. Statistical analysis consisted of ANOVA with repeated measures and pairwise comparison calculated with Bonferroni adjustment. Variables of interest included: mean stimulation current, subjective pain, skin temperature, $V0_2$, respiratory quotient, and galvanic skin resistance. Results revealed that oxygen consumption ($V0_2$) was consistently greater during 4-min contractions with the sine waveform as compared to Russian or square waveforms. Respiratory quotient or carbon dioxide produced in relation to oxygen consumed did not significantly differ between different waveforms. Mean skin temperature at the forehead increased, however increases were not statistically significant (Square waveform: .18°C and sine waveform .09°C). Russian stimulation results produced the greatest increase in galvanic skin resistance. In conclusion the sine waveform was recommended over the other waveforms to stimulate isometric contractions.

Gregory [3] investigated the effect of vary pulse duration and frequency on muscular torque and fatigue in 10 healthy male subjects (29.9 ± 6.7 yrs). Isometric torque measurements of the quadriceps femoris were obtained on a Biodex isokinetic dynamometer (Knee flexion 80°). A Grass S8800 stimulator, capable of generating different frequencies (10, 20, 30, 40, 50, 60, 70, and 100Hz) and pulse durations (100, 200, 300, 400, 500, 600, and 700 microseconds) was used delivered the stimulation.

Combinations of the different frequencies and pulse durations were randomly delivered for 500 ms. A 70Hz/ 600 microsecond pulse was delivered at the beginning, middle and end of the protocol to assess fatigue. Following fatigue test, participants were asked assess pain on visual analog scale and McGill Pain Questionnaire. Data were analyzed via *t*-tests with the alpha set at $\alpha = 0.05$. Researchers found that the interaction of pulse duration and frequency (total charge) was a strong predictor of muscular torque production. As total charge increased muscular torque increased. Authors theorized that torque production was generally lower at lower frequencies due to the inability for action potentials to summate. A drawback of higher stimulation frequencies was increased muscular fatigue. Authors reported that no pain was produced by any of the stimulation parameters presented in the study and concluded that total charge (pulse frequency and pulse duration) should be set to avoid fatigue.

Muscular torque production parameters for NMES to increase torque have not been yet established. Research indicates consideration of longer pulse durations and higher current frequencies to increase muscular torque production. As these parameters are increased, discomfort also increases. Therefore a balance between torque production and stimulation comfort should be established when strength training with NMES. Russian currents are a form of alternating current NMES burst modulated to increase comfort of stimulation without effecting muscular torque production (Characterized as a 2,500 Hz AC burst modulated at 50 Hz).

"Russian" NMES in Healthy Individuals

R. Keith Laughman JWY, Tom R. Garrett, and Edmund Y.S. Chao. [50] investigated the use of Russian current for strength training healthy individuals (28 males and 30 females, mean age 23.5 yrs). Subjects trained five days a week for five weeks in a stimulation group or isometric exercise group. The stimulation group received electrical stimulus for 15-seconds with 50-seconds. Stimulation electrodes were placed on the anterior thigh with the proximal electrode around the femoral triangle and distal on margin of vastus medialis. Maximum voluntary isometric contraction (MVIC) was measured at 60° of knee flexion with a load cell based device. After an analysis of covariance was performed on linear regression lines of muscular torque, results revealed that the stimulation group MVIC increased 22%, the isometric exercise group increased 18%, control group 2%.

Further support of Russian stimulation comes from Soo CL, Currier DP, and Threlkeld AJ. [51]. They used fifteen healthy subjects who trained two times a week for five weeks. Subjects in the stimulation group received eight electrically stimulated contractions for 15-seconds with a 5-second ramp up. The training stimulus provided by electrical stimulation was estimated to be around 50% of MVC. A control group receiving no treatment was also used in the study. An analysis of covariance was performed to analyze post treatment muscular torque with the alpha level set at .05. Posttest results indicated that stimulation was capable of increasing muscular torque in healthy individuals. Interestingly, relatively few training sessions resulted in strength gains. In comparison to Laughmen et al. study, the amount of training sessions is drastically reduced.

Snyder-Mackler L, Garrett M, and Roberts M. [52] investigated three different NMES devices and their ability to elicit a training load to 20 healthy individuals (11 males and 9 females, mean age 28.7 yrs. Training loads were established as muscular torque produced by electrical stimulation relative to Maximum Voluntary Isometric Torque expressed as %MVIT. Devices used were the Electrostim 180-2, Chattanooga VMS, and the Nemectrodyn 7. Characteristic to the Electrostim 180-2 is a 2,500 Hz alternating current (200 μsec phase duration) providing 50 bursts per msec or Russian stimulation. Electrical stimulation was applied to quadriceps femoris and isometric knee extension torque was measured on the Cybex II Isokinetic Dyanmometer. A one-way ANOVA was used analyze torque production between stimulators. The Electrostim 180-2 produced the greatest %MVIT among the three stimulators. Although the Electrostim was able to provide the highest mean current, they found that phase duration also contributed to maximum peak torque output.

All studies in this review incorporated healthy individuals, however, the level of training was not mentioned by any of the authors. Interestingly Soo et al. reported that Russian stimulation at 50% of maximum voluntary contraction was effective enough to elicit a stress and increase strength after two weeks. In a literature review conducted by Ward and Shkuratova [53] a study by Dr. Yakov Kots involved Russian currents and he claimed that Russian currents enabled increases maximum voluntary contraction by 40% in elite athletes. Unfortunately his methodology was not documented clearly and studies to date have not been able to replicate his results. An alternative form of NMES is a known as a direct current characterized as a high peak current and theorized to penetrate deeper muscular tissue to recruit more motor units and increase muscular torque output.

Direct Current/ High Volt Galvanic Stimulation

Mohr T, Danzl L, Akers TK, and Landry R. [54] studied the effects of High Volt Galvanic Stimulation [(HVGS) direct current] on MVIT with 19 healthy subjects (5 males and 14 females, aged 21-31 yrs). Maximum voluntary isometric knee extension and HVGS driven contraction was measured on a Cybex Isokinetic dynamometer at 60° of knee flexion. Three different stimulation frequencies were implemented (50 Hz, 80 Hz, and 120 Hz). The use of HVGS did not produce a training stimulus equivalent to MVC. Data were analyzed via ANOVA, results indicated that HVGS produced torque equivalent to 85% of MVIC. The average contractile force ranged from 44.1-47.2% within the three different stimulation frequencies. The highest average force contraction was achieved with frequency of 120 Hz.

Mohr T, Carlson B, Sulentic C, and Landry R. [55], conducted a three week (15 sessions) study with 18 healthy females (21-29 yrs) divided into a HVGS and a voluntary isometric contraction groups. Ten electrically stimulated contractions were held for 10-seconds with 10-seconds of rest between each contractions (stimulation group). A Microdyne stimulator was used to generate a twin peak pulse with a short phase duration and current intensity of 0 - 2,500 mA. The isometric exercise group condition did the same exercise without electrical stimulation. A one-way ANOVA was used to analyze pre and post torque measurements. A Cybex II dynamometer was used to assess MVIC at 60° of knee flexion. Results indicated that HVGS was not as effective as voluntary isometric exercise [HVGS .7% improvement compared to 14.7% in voluntary exercise.

Wong [56] compared high volt pulsed galvanic stimulation (HVPGS) to low volt electrical stimulation (LVNMS) within 24 healthy subjects (9 males and 15 females, mean age 24) (Two participants dropped out). Both HVPGS and LVNMS devices were used to stimulate the quadriceps and soleus muscles separately. Subgroups were formed and consisted of 10 subjects in the quadriceps stimulation group and 12 in the soleus stimulation group. Involuntary peak torque was measured on a Cybex isokinetic dynamometer. Subjects received two random six-minute stimulation sessions with either HVPGS or LVNMS. Stimulation was applied for 10-minutes and participants were asked to rate perceived pain on visual analog scale. Perceived discomfort and muscular torque production data were analyzed via *t*-test . Treatment preference was determined with Chi-square analysis. Results indicated that HVPGS was capable of producing greater peak isometric muscular torque (soleus) and was more comfortable than LVNMS. Interestingly this effect did not carry over to the quadriceps femoris, where no significant differences were observed between the two stimulators.

Alon [57] investigated the effects of different electrode sizes on pain and excitatory response via a HVG stimulator (Model 450 Microdyne, Monophasic pulsed 5-20 μsec phase duration, peak volt 500 mA). Subjects were14 healthy students (8 females and 6 males, mean age 25.2 yrs). Four different sized electrode were used (3 x 3 cm, 6 x 6 cm, 9 x 9 cm, and 5 x 16.2 cm). Subjects' knee extensors positioned at 30 degrees of knee flexion were stimulated with the maximum tolerated intensity. After a Newman-Kuels post-hoc test, significant results were indicated higher electrical stimuli dosages when 5 x

16.2 cm and 9 x 9 cm electrodes were used to deliver electrical stimulus with the least amount of discomfort. Maximum voluntary contraction increased 13.3% after all the treatments were completed.

As with Russian currents, direct current studies reviewed involve healthy participants. Although, a lack of research is available on strength training with direct current NMES. Direct current stimulation is more commonly used in delivering medications transdermally [58] (iontophoresis) and treating decubitus ulcers [59, 60]. The research that has been done indicates strength training with direct current imposes an adequate amount of stress to increase strength. Although NMES in general is capable of increasing strength, gains do not usually exceed gains from voluntary exercise. An alternative method involving NMES utilized concurrently with a voluntary contraction is termed superimposed training. The idea of this type of training revolves around muscular inhibition and optimal motor unit recruitment. Motor unit recruitment deficiencies within a voluntary contraction are theoretically addressed by electrical stimulation.

Superimposed Alternating Current Muscular Strength Training

Currier and Mann [33] studied 34 (15 females, 19 males, mean age 22.5 yrs) subjects trained three days a week for five weeks. Subjects were divided into four groups: the control(CON) group received no treatment, the isometric exercise group (E) performed isometric knee extension, the stimulation group (S), and the isometric exercise with stimulation group (ES). Training consisted of 10 isometric contractions for 15-second with 50-seconds of rest between each repetition at 60° of knee flexion. Testing was completed statically/isometrically (0°/sec at 60 degrees of knee flexion) and dynamically (100, 200, and 300°/sec) on a Cybex II dynamometer. All participants were given three attempts to achieve maximum knee extension with the largest torque score recorded. Verbal encouragement was given during testing. An analysis of covariance was used to evaluate differences between pre and posttest results. Thigh girth measurements were recorded with no significant changes after five weeks of training. Static/isometric torque increased over time and was statistically significant compared to CON. However, no statistical differences were revealed between training groups in isokinetic strength at 100°/sec, 200°/sec, and 300°/sec.

Currier DP, Lehman J, and Lightfoot P. [24] investigated the effects of isometric and superimposed isometric exercise on 37 healthy students (31 females and 6 males mean age 21.9 yrs) in a two week study. Subjects were randomly assigned to one of three groups: Control group (CON, 14 females), isometric exercise (Group B, 7 females and 4 males), and isometric exercise combined with electrical stimulation (Group C, 10 female and 2 males). Exercise was performed on a Cybex Dynamometer II and consisted of isometric knee extension at 60 degrees and 6 repetitions at 6 seconds per a rep. Participants rested 10 seconds between each rep. Electrical stimulation was characterized as a rectangular wave with a pulse frequency 25 pulses per second. Intensity of stimulation was adjusted accordingly to individuals' tolerance. Upon completion of 10 training sessions, subjects performed a one repetition maximum isometric contraction for 6 seconds. A one-way ANOVA was used to analyze the data. Results indicated significant differences between group CON and both groups B and C. While group B increased strength 19% and group C 21 % no differences were revealed between Statistical analysis revealed no significant difference between groups B and C.

Willoughby and Simpson [12] studied the effects of superimposed training on 20 trained collegiate female track athletes. Knee extensions consisting of three sets of eight to ten repetitions at 85% of 1 repetition maximum were performed three times a week for six weeks. Strength testing was performed on an isotonic knee extension machine and power and function were assessed via vertical jump tests. Tests were performed every two weeks. A 4 x 4 ANOVAs were used to analyze the muscular torque and vertical jump data. Significant interaction effects were followed by Neuman-Keuls post hoc test. Results indicated significant increases in 1 repetition maximum knee extension torque with the electrical stimulation in concentric and eccentric phases of a knee extension exercise. In this study, superimposed contractions were more effective than traditional voluntary exercise to increase muscular torque. Vertical jump in the superimposed groups also improved (25%) more than the groups not superimposed electrical stimulation (Weights 9% and NMES 2%). Willoughby and Simpson speculated that the effectiveness of superimposition on muscular torque output was due to recruitment of additional motor units that were not normally recruited within a MVC.

Willoughby and Simpson [11] also studied the effects of superimposed training on 24 trained male (20 ± 2.42 yrs) basketball players. Subjects performed three sets of eight to ten repetitions of biceps curls (preacher bench) at 85% of 1-repetition maximums three times a week for six weeks. The superimposed electrical stimulus was imposed on the eccentric and concentric phase of exercise. A two-way ANOVA with repeated measures was used to analyze the data. Muscular strength training by superimposed contraction resulted in a 1-RM greater than a non-electrically stimulated bicep curl. Authors concluded that superimposed training was a better method in strength training than resistive weight training alone.

Hartsell [31] investigated the effects of superimposed quadriceps femoris isometric training in 21 healthy untrained males (age 18-35 yrs). Training was performed five days a week for six weeks. Exercise consisted of a total of ten isometric knee extensions with each contraction held for ten seconds and a 50-second rest period between contractions. A 2-factor MANOVA was used to analyze the treatment data. Superimposed muscular strength gains reported were comparable to voluntary exercise. The study verified the concept that untrained subjects improved quadriceps femoris strength more than trained subjects. Furthermore, the results revealed a positive trend toward a mono-polar electrode configuration over a bi-polar setup for strength training. Muscular power and endurance were measured through isokinetic testing at 30°/sec and 180°/sec with no significant differences between pre and post testing.

Bezerra P, Zhou S, Crowley Z, Brooks L, and Hooper A. [15] investigated the effects of superimposed electrical stimulation of the quadriceps femoris at 60 degrees of knee flexion with 30 untrained male participants. Training involved three sets of ten maximum voluntary isometric knee extensions (contraction held for five seconds/ rest five seconds between contractions/ one minute of rest in between sets) performed three times a week for six weeks. Testing consisted of a knee extension/ flexion MVIC at 60 degrees of knee flexion. An MRI was used to assess physiological changes in quadriceps femoris. Training effects were compared to different treatments and between legs by a 3 factor repeated measures ANOVA. Researchers reported superimposition of quadriceps knee extension produced similar results as voluntary exercise, similar to Hartsell's study results[31]. Furthermore an added component of this study was the measurement of cross education effect in the uninvolved limb. Results indicated muscular strength gains in the untrained limb were greatest in the superimposed condition. Since no significant differences were revealed in cross-sectional area the authors attributed muscular strength gains to neuromuscular adaptation.

Herrero AJ, Martin J, Martin T, Abadia O, Fernandez B, and Garcia-Lopez D. [25] conducted a study of 20 untrained males (21.4 ± 1.4 yrs) who performed ten repetitions of eight sets of knee extensions with three minute rest periods between sets. Superimposed NMES was applied to bilateral knee extensions four times a week for four weeks. Stimulation was applied in the concentric phase of exercise and consisted of a biphasic symmetrical square wave, 120 Hz frequency, and 400-microsecond pulse width. A two-way ANOVA was used to analyze the data with the alpha level set at $p \leq .05$. Results indicated significant increases in MVIC and gains greater than training without superimposition. Researchers also evaluated changes in functional movements such as squat jump, counter movement jump, counter movement jump with free arms, and 20-meter sprint. The authors concluded that superimposed muscular training impairs functional movements. A detraining period or two-weeks after training was also analyzed and results suggested muscular strength gains lasted longer with the superimposed group.

Locicero [61] studied 30 healthy subjects (20 females, 10 males, mean age 24.5 yrs) who participated in two exercise sessions. During the first session, subjects were familiarized with the Cybex Dynamometer. In the second session the subjects performed knee extensions (non-dominant leg) isokinetically at three different velocities: 0, 60, and

240 degrees/sec. During isometric knee extension testing the knee was positioned at 60 degrees of flexion. Proximal NMES electrodes were placed over the femoral nerve trunk distal to inguinal ligament. The distal electrode was placed five cm above superior pole of patella. Current intensity was increased to the maximum amount that subject could tolerate without perceiving pain. Knee extension was performed with electrical stimulation. Independent variables include NMES and voluntary contractions to generate muscular peak torque. Data analysis consisted of repeated measures, multifactor ANOVA with the alpha level set at $p<0.05$. Results indicated that muscular torque output in superimposition of NMES and voluntary contractions yielded similar strength gains as voluntary contractions. Isokinetic velocity at 240 degrees/sec was more effective in producing muscular torque outputs than at 60-degrees/ sec.

Paillard T, Lafont C, Soulat JM, Costes-Salon MC, Mario B, Montoya R, and Dupui P. [62] investigated the effects of electrical stimulation in 32 healthy women (62-75 yrs). Participants were randomly assigned to one of three groups: SC group climbed up and down 300 real stairs (height 20 cm), ES group portable electrical stimulator applied for 15 minutes (stimulation of rectus femoris and vastus medialis), and SC + ES group climbed stairs with concurrent electrical stimulation. Electrical stimulation parameters consisted of a biphasic symmetrical square wave (350 microsecond phase duration and frequency of 20Hz). Each protocol was performed four times a week for six weeks. Testing consisted of lean body mass measurement via Dual Energy X-ray Absorbtiometry (QDR 4500, Fan Beam X-Ray Bone Densitometer) and quadriceps femoris strength assessment via Cybex isokinetic dynamometer (Isometrically 20° and 100°, Isokinetically 60°/sec and 240°/sec). A 3-factor ANOVA was used to analyze parameters of each condition. No significant differences were reported within all three groups, however a trend towards improved endurance (isokinetic at 60°/sec) with participants within SC+ ES group was seen. Authors concluded that the SC + ES technique may be more effective in preventing muscular atrophy than promoting hypertrophy in healthy individuals.

Valli P, Boldrini L, Bianchedi D, Brizzi G, and Miserocchi G. [63] evaluated the effects of low intensity electrical stimulation on strength training with two different protocols. The first protocol involved 13 healthy participants (7 females and 6 males, mean age 50.6 yrs old). All participants underwent 11 days of bilateral quadriceps electrical stimulation. Each stimulation session lasted 30 minutes with stimulation frequency increasing 60 to 90Hz for a 7-second contraction and 15-second rest period at 20Hz. The second protocol involved six (separate from protocol 1) healthy males, three performing a voluntary contraction with electrical stimulation superimposed and the other three placed in a control group. Subjects performed ten contractions at 60% of F_{max} with electrical stimulation (electrical stimulation protocol identical to protocol 1). Control group performed 10 contractions at 60% of F_{max}. Quadriceps femoris isometric torque was measured with a Cybex II Isokinetic dynamometer (knee flexion 60°). Oxygen uptake (VO_2 Max) and heart rate were also measured. Protocol 1 increased F_{max}, with gains more apparent after the 6th day of training. Oxygen consumption increased 20% during electrical stimulation and a new steady state was achieved after 20-30 seconds. No significant changes in heart rate were reported. In protocol 2 no significant changes in F_{MAX} was reported with participants training at 60% of F_{MAX}. Conversely a significant increase (5%) in F_{MAX} was observed with participants placed in the ES + voluntary contraction group. A limitation of this study is the short training period (11 days). Authors concluded that low intensity stimulation could be a useful rehabilitation approach for individuals that cannot tolerate high intensity electrical stimulation.

Nobbs and Rhodes [26] compared 27 healthy moderately trained females (19-27 yrs) participants were placed in three groups [Electrical stimulation plus isokinetic exercise (IS + IE), isokinetic exercise (IE), and electrical stimulation (ES)]. Participants trained 18 sessions over six weeks. Testing was performed on initial visit pre-test, three week mid-test, and six week post-test. Participants were tested at 30°/sec, 100°/sec, and 180°/sec with the later two settings for power on a Cybex® II Isokinetic Dyanamometer. Thigh girth was taken at 1 cm distal to the gluteal line and 20 cm superior to base of the patella. A Multitone Multifaradic unit provided stimulation. Electrodes were placed over motor points of vastus medialis, rectus femoris, and vastus lateralis. Subjects placed in the stimulation group received ten, 10-second contractions at a frequency of 60 Hz with a 50-sec rest period. Isokinetic exercise group maximally extended their knees against the dynamometer at 30°/sec six times for three sets. The ES + IE group performed same exercise as IE, but without stimulation. Data were analyzed using a multivariate ANOVA and revealed no significant differences at high velocities indicating that power-training benefits may be limited to training velocity. Results also indicated no difference in time to peak tension. Prior to study, preferential fast-twitch fiber recruitment was theorized with NMES, but this study indicated that slow twitch fibers cannot be bypassed and recruitment solely of fast-twitch fibers is not possible. No significant increase thigh girth was reported. Study results indicated that superimposed isokinetic exercise was not any more effective than isokinetic exercise alone.

Utilization of an alternating current to stimulate a superimposed contraction and increase muscular torque greater than voluntary contractions remains inconclusive. Differences in research methods may factor into how superimposed technique effect muscular torque output. Willoughby and Simpson incorporated electrical stimulation in both concentric and eccentric phases of exercise. Herrero et al. only applied electrical stimulation during the concentric phase of exercise and muscular torque gains improved over the voluntary exercise group. Pillard et al. [17] conducted a superimposed training literature review and concluded that strength gains with superimposed training were not greater than gains experienced with voluntary exercise. Similar to involuntary NMES studies, researchers incorporated direct current into superimposed training with aspirations of increasing muscular torque greater than voluntary exercise.

Direct Current Superimposed Training

Wolf SL, Ariel GB, Saar D, Penny MA, and Railey P. [18] investigated the effect superimposed training had on 27 male trained professional tennis coaches. Participants were randomly divided among three groups (E/S received superimposed exercise, E or exercise without electrical stimulation, and CON group who did not exercise. Direct current superimposition was incorporated in an isotonic squat exercise with electrical stimulus applied to the concentric phase. Participants trained for four days a week for four weeks. Training consisted of four sets with varied resistance provided by hydraulic pressurized squat machine (First set; 75°/ sec, Second set; 50-10°/ sec (deceleration); Third set 25-75°/ sec (acceleration); Fourth set 35°/sec). Eighteen measures were taken for testing that involved max force, average force, and velocity of contraction and sprint time. A two-factor ANOVA with repeated measures on one factor was used to analyze the data. Group E/S and E made significant gains in max force, velocity of contraction, and sprint time. The authors concluded that superimposed exercise was equally as effective as voluntary training.

Appendix: A

INFORMED CONSENT
To Participate in a Research Study

Department of Kinesiology and Rehabilitation Science, University of Hawaii at Mānoa
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I. Investigator

Principal Investigators: Rich Wu, ATC; Yukiya Oba, MS, ATC, CSCS; Iris F. Kimura, PhD, ATC, PT; Ronald K. Hetzler, PhD, FACSM, Darryl M. Kan, MD; Christopher D. Stickley, PhD, ATC, CSCS, Kazuhiko Yanagi, MAT, ATC, CSCS

II. Title

The Effects of Direct Current and Alternating Current Superimposed Isometric Training on Maximum Voluntary Isometric Torque and Electromyography Activity

III. Informed Consent

I am being asked to participate in this study because I am a healthy male between the ages of 18-34 years old and have strength trained for the last 6 months. This study is being conducted through Kinesiology and Rehabilitation Science Department at the University of Hawaii at Mānoa. The purpose of this informed consent form is to provide me with information about this research to help me decide if I would like to participate in this study. This form is called an informed consent form. If there are any words or sections in this consent form that I do not understand or want to clarify, I will ask the primary investigator to explain them. My participation will assist Rich Wu, ATC in partial fulfillment of this thesis required for his master's degree. If I understand the study and agree to take part in this study, I will be asked to sign this consent form. It is important that I understand that taking part in this study is at my own free will. I may decide not to participate, or I may decide to withdraw from study at any time without any repercussions.

IV. Purpose and Overview of Study

The purpose of this study is to investigate the effect of concurrent use of (superimposed) direct current and alternating current electrical stimulation on isometric knee extension strength after a 6-week training period in a healthy intermediately (6 months of strength training) trained male population. Superimposed muscular training has been utilized as a method to supplement voluntary muscular contraction by electrically stimulating additional motor units to optimize the contraction and facilitate further increases in muscular strength. The current study consists of training period (6-week isometric knee extension training) and testing periods (before, during, and after the training period). Thigh circumference, electrical muscular activity, and isometric knee extension strength will be assessed at each testing period. Alternating current and control conditions will also be studied to compare results between the different types of stimulation and exercise-only groups.

V. Procedures

If I decide to participate in this study, I will perform the following tests and protocol:

Data Collection: I will be asked to report to the University of Hawaii at Mānoa, Kinesiology and Rehabilitation Science Laboratory for testing. I will then review the exercise contraindications outlined by the American College of Sports Medicine with the investigator and be asked to fill out a Pre-participation Medical History and Physical Activity Readiness Questionnaire. If I am unclear with any of the contraindications, I will ask for clarification. A medical doctor will screen my questionnaire for any contraindications that may conflict with me participating in this study. Contraindications include history of knee surgery, knee injury, pacemaker, history of blood clots, pregnancy, neurological disease, cardiopulmonary disease, and the stated inability to complete this study. Once I am cleared to participate in this study, my height, body mass, and blood pressure will be measured by the principal investigator who is a National Athletic Trainers' Association Board of Certification Certified Athletic Trainer. Testing and training will be standardized to the right leg. Prior to testing I will complete a 5-minute warm-up on a cycle ergometer. The circumference of the my right thigh will be measured by a tape measure and recorded at 5, 10, 15, and 20 cm above my knee cap. Those measurement points will be marked with a permanent marker. For electrical muscular activity measurement, I will be asked to lie on my back and relax on a treatment table for electrode placement preparation. The hair on the front portion of my thigh will be shaved with my permission for electrode placement. If I decide that I do not want my hair shaved, I will be excluded from study without any repercussions. Skin will be cleaned with alcohol pads and scrubbed by a coarse sponge. Once skin preparation is complete, electrodes will be placed and the electromyography unit will be connected. I will be instructed on how to perform voluntary isometric contraction of knee extension on the Biodex Isokinetic Dynamometer. Once I become familiarized with the strength test protocol and all my questions are answered, the testing session will begin. Electrical muscular activity will be recorded during the strength test. Initially, I will perform 3 sets of 10-second isometric contractions at approximately 50% of my full strength for a warm-up followed by a 3-minute rest period. Testing will begin after a 3-second count down. I will press the immovable dynamometer arm (0 degrees per second/isometric) as hard as I can for 10 seconds. This will be repeated 3 times with 2-minutes of rest in between each set. A verbal count down will be given prior to the start of all testing and training.

Leg Extension Training: Training will begin within 2 days of the initial testing session. Training with or without electrical stimulation imposed for me will be determined via random order. I will be expected to report weekly for 3 exercise sessions per week for 6 weeks to perform isometric leg extension exercises. I will be positioned on a treatment table sitting with my legs fully extended and trunk upright perpendicular to the table. I will be asked to dorsi-flex my ankle (Bring toes toward shin) and contract my thigh (quadriceps femoris) by pressing the back of my knee onto the treatment table as hard as I can. Training sessions consists of 3 sets for 10 repetitions with 2 minutes of rest in between each set. Each repetition will be held for 5-second duration. If I am placed into either a direct current or alternating current stimulation group, my leg exercise will be performed concurrently with electrical stimulation. Electrical current will be delivered via direct or alternating current neuromuscular electrical stimulation devices that are regulated by Food and Drug Administration. Electrode placement for the training will be determined based on motor point locations. Motor points are the locations that a given level of electrical stimulation can cause the strongest contraction within quadriceps muscles. During the training, comfort level will be constantly monitored by the investigator. Level of stimulation intensity will be based on my perceived level of stimulation comfort and will be increased accordingly to the strongest current intensity without causing pain. The following script will be read to me to help facilitate the achievement of adequate electrical stimulation intensity without causing pain, ***"The intensity will be increased slowly until you request that it be stopped. Initially you will feel a tingling (similar to leg regaining feeling after falling "asleep") sensation, the sensation should be strong, but should not cause any pain."*** When and/or if the stimulation intensity is increased, I will be asked to rate the amount of pain I am experiencing on the visual analog pain scale. If I indicate any level of pain on visual analog pain scale, the stimulation will be decreased or terminated. Electrical stimulation will be on during exercise and rest periods. During the rest periods, I will be given an opportunity to increase stimulation intensity as I get used to the stimulation. Initial stimulation intensity, as well as any changes in stimulation intensity will be recorded on electrical stimulation intensity form. If I am placed into the control group, I will perform the identical leg extension exercise, repetitions, and sets without electrical stimulation. Training will involve 3 sessions per week separated by at least 1 day and last 30 minutes.

VI. **Risks**

Possible risks include any risk associated with weight training and exercise. I may experience slight discomfort and soreness following the day of testing. The risks from neuromuscular electrical stimulation are quite low. However

I may experience slight skin irritations such as redness and discomfort where the pads are placed.

VII. Research Related Injury

In case of any physical injury during this study, immediate medical treatment including first aid, CPR and, an automated external defibrillator (AED) is available on site. If I am injured as a result of being in this study, immediate on-site care is available for my injuries by National Athletic Trainers' Association Board of Certification Certified Athletic Trainers. University of Hawaii at Mānoa does not possess any policy designed to cover the medical treatment required as a result of injuries incurred in this study. I will utilize my personal medical insurance for my research related injuries. If my insurance will not pay for these costs, I will be responsible for the cost.

VIII. Benefits

I may not directly benefit from this study although I can gain knowledge and experience from being part of this study. Results from study will benefit doctors, athletic trainers, physical therapist, and strength coaches in providing results that may aid in the decisions of the use of electrical stimulation in rehabilitation or strengthening.

IX. Safeguard

I will be monitored closely by health care providers (National Athletic Trainers' Association Board of Certification Certified Athletic Trainer), while I am in this study.

X. Confidentiality

All my research information will be kept confidential to the extent allowed by law. My personal information will not be given out to anyone without my written permission. However, the University of Hawaii Human Studies Program has the right to review research records. During the study I will be identified by an assigned code on medical documents only identifiable by research personnel. All information obtained from me will be stored in a lock cabinet located in the Kinesiology and Rehabilitation Science department at the University of Hawaii at Mānoa. All data acquired from study will be kept for a maximum of 5 years at which data will be disposed. Information gained from study may be published in journals or disclosed in forums; however publications and forums will keep participants name and other information that may reveal participant identity confidential.

XI. Compensation

I will receive no compensation (direct or implied) for completing this study.

XII. Biological Specimens

I will not be asked to provide my biological specimens such as blood, saliva, and urine in this study.

XIII. Certification

Participation is voluntary; refusal to participate will involve no penalty to myself. There are no alternatives to the procedures in this study. I may withdraw my consent and discontinue participation in this research project at any time without negative consequences. I have the right to ask questions concerning the procedures at any time and have any questions answered to my satisfaction. If any new findings are developed during the time that I am in this research project, which may affect my willingness to continue to be in the study, I will be informed as soon as possible. All testing will be scheduled at my convenience when I am on campus. No reimbursement for parking is available and I will not be compensated for my time. If I desire further information about this research project, I may contact Iris F. Kimura at (808) - 956-3797. If I would like to talk with someone about my rights of being a subject in this study I may contact the UH Human Studies Program at (808)-956-5007, or by email: uhirb@hawaii.edu

RESEARCH PARTICIPANT INFORMED CONSENT

Department of Kinesiology and Rehabilitation Science
University of Hawaii at Mānoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606

I understand that if I am injured in the course of this research procedure, I alone may be responsible for the costs of treating my injuries.

By signing below, I certify that I have read and understand this informed consent form and all my questions have been answered to my satisfaction. I am aware of my rights and I choose to participate in this research project.

The Effects of Direct Current and Alternating Current Superimposed Isometric Training on Maximum Voluntary Isometric Torque and Electromyographic Activity

____________________________ ______________
Printed name of individual participant Date

____________________________ ______________
Signature of individual participant Date

I have explained and defined in detail the research procedure in which the participant has agreed to participate and have offered her or him a copy of this informed consent form.

____________________________ ______________
Printed Name of individual investigator Date

____________________________ ______________
Signature of individual investigator Date

Testing and Training Outline

	Pre-Test (Baseline)	Weeks 1-3	End of Week 3 (Mid-Test)	Week 3-6	End of Week 6 (Post-Test)
Thigh Circumference	x		x		x
Knee Extensor Strength	x		x		x
Electromyograhpy (Muscular Activity)	x		x		x
Knee Exercise with/ or without Electrical Stimulation		x		x	

Appendix: B

INSTRUMENTATION

Accelerated Recovery Performance RX100 (ARP) (Apple Valley, MN) device was used to provide direct current in this study. This is a NMES device that delivers a high frequency direct current to stimulate muscular tissue and was approved by the Food and Drug Administration. This device incorporates a background current set at 10,000 kHz with an adjustable main current frequency of 40 to 500 Hz. A knob located on the faceplate of the device is used to adjust current amperage or intensity. Electrical current is transferred from the device to the skin by two (left and right) wire leads with two self-adhering carbon film square electrodes (5 cm x 5 cm) at the end of each lead.

Forte 200 Stimulator(ACS) (DJO LLC, Vista, CA) was used to provide alternating current in this study. This is a NMES device that delivers a high frequency alternating current to stimulate muscular tissue. This device distributes a 2,500 Hz alternating current with an inter-burst of 50 Hz. Current intensity of 0-100 mA may be adjusted via a button located on the faceplate of the device. Electrodes are identical to direct current stimulator electrodes described above (ARP).

Biodex System 3 Pro Dynamometer. The Biodex System 3 Pro dynamometer (Biodex) (Biodex Medical Systems, Inc., Shirley, New York) is an electrically controlled device used to assess muscular torque output (isokinetically, isotonically, isometically). The device consists of an electrically controlled dynamometer that various levers (mechanical arms) may be attached to and moves around it's axis. Mechanical arm velocity is controlled by computer software (Rev 3.33 FW version 1.56) and velocity can range from 0 to 360 degrees per second and 0 to 180 degrees (based on mechanical arm selection). Torque output is measured in foot-lbs and newton-meters, via the force generated against the mechanical arm set at specific velocity and range of motion.

Biopac MP30 EMG. The Biopac MP30 EMG (BIOPAC Systems, Inc., Santa Barbara, CA) unit is device used to collect surface integrated electromyography (iEMG) signals used to assess muscular activation (microvolts, μV). Three sets of electrode wire harnesses (one for each of three channels) consisting of positive, negative, and ground leads are used to illicit stimulation. The electrical lead signals are obtained via chloride silver disposable circular electrodes (Quick-Trace, Quinton Instrument Co., Seattle, WA, Diameter 6.35 cm). Biopac Student Lab Pro software version 3.6.7 is used to capture data from Biopac MP30 (Biopac Systems Inc., Goleta, CA). Electromyographic signals are processed with Acknowledge software. Previous research findings have found surface EMG to be moderately to highly reliable (r=. 58-.99) [64].

Visual Analog Pain Scale (VAPS). The VAPS is scale consisting of a 100 mm horizontal line with verbal descriptors at each end used to assess pain/discomfort. One end of the line represents no pain and the other end represents maximum pain associated with the activity. Participants are provided this scale and are asked to mark the level of pain they experience. Reliability and validity of the instrument have been demonstrated in previous research (Intraclass Correlation Coefficient= .97) [65-67].

Appendix: C
American College of Sports Medicine's Guidelines for Exercise Testing and Prescription, 7th Edition
Contraindications to Exercise

Absolute

- A recent significant change in the resting ECG suggesting significant ischemia, recent myocardial infarction (within 2 days), or other acute cardiac event
- Unstable angina
- Uncontrolled cardiac disrhythmias causing symptoms or hemodynamic compromise
- Symptomatic severe aortic stenosis
- Uncontrolled symptomatic heart failure
- Acute pulmonary embolus or pulmonary infarction
- Acute myocarditis or pericarditis
- Suspected or known dissecting aneurysm
- Acute systemic infection, accompanied by fever, body aches, or swollen lymph glands

Relative[1]

- Left main coronary stenosis
- Moderate stenotic valvular heart disease
- Electrolyte abnormalities (e.g., hypokalemia, hypomagnesemia)
- Severe arterial hypertension (i.e., systolic BP of >200 mm Hg and/or a diastolic BP of >110 mm Hg at rest)
- Tachydysrhythmia or bradydysrhythmia
- Hypertrophic cardiomyopathy and other forms of outflow tract obstruction
- Neuromuscular, musculoskeletal, or rheumatoid disorders that are exacerbated by exercise
- High-degree atrioventricular block
- Ventricular aneurysm
- Uncontrolled metabolic disease (e.g., diabetes, thyrotoxicosis, or myxedema)
- Chronic infectious disease (e.g., mononucleosis, hepatitis, AIDS)
- Mental or physical impairment leading to inability to exercise adequately

1. Relative contraindications can be superseded if benefits outweigh risks of exercise. In some instances, these individuals can be exercised with caution and/or using low-level end points, especially if they are asymptomatic at rest.

American College of Sports Medicine's Guidelines for Exercise Testing and Prescription, 7th Edition
Indications for Terminating Exercise Testing

Absolute

- Drop in systolic blood pressure of >10 mm Hg from baseline[1] blood pressure despite an increase in workload, when accompanied by other evidence of ischemia
- Moderately severe angina (defined as 3 on a standard scale)
- Increasing nervous system symptoms (e.g., ataxia, dizziness, or near syncope)
- Signs of poor perfusion *cyanosis or pallor)
- Technical difficulties monitoring the ECG or systolic blood pressure
- Subject's desire to stop
- Sustained ventricular tachycardia
- ST elevation (+1.0 mm) in leads without diagnostic Q-waves (other than V_1 or aVR)

Relative

- Drop in systolic blood pressure of >10 mm·Hg from baseline[1] blood pressure despite an increase in workload, in the absence of other evidence of ischemia
- ST or QRS changes such as excessive ST depression (>2 mm horizontal or down sloping ST-segment depression) or marked axis shift
- Arrhythmias other than sustained ventricular tachycardia, including multifocal PVCs, triplets of PVCs, supraventricular tachycardia, heart block, or bradyarrhythmias
- Fatigue, shortness of breath, wheezing, leg cramps, or claudication
- Development of bundle-branch block or intraventricular conduction delay that cannot be distinguished from ventricular tachycardia
- Increasing chest pain
- Hypertensive response (systolic BP of >250 mm Hg and/or a diastolic BP of >115 mm Hg).

1. Baseline refers to a measurement obtained immediately before the test and in the same posture as the test is being performed.

Participant ID: ____

Appendix: D

Pre-Participation Medical History Form/ Physical Activity Readiness Questionnaire

Participant Information

ID number ______________
Date of Birth:____________ Age (years) ______ Sex: M / F
Home Address:________________________
City/State/Zip:______________________ Email: ________________
Home/Cell Phone (__) ___________
Emergency Contact Person/Relationship/Phone Number:
____________________________________(__)___________

Physical Activity Readiness Questionnaire (American College of Sports Medicine, 1997)

Please read the questions carefully and answer each one honestly.

YES NO

☐ ☐ 1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

☐ ☐ 2. Do you feel pain in your chest when you do physical activity?

☐ ☐ 3. In the past month, have you had chest pain when you were not doing physical activity?

☐ ☐ 4. Do you lose your balance because of dizziness or do you ever lose consciousness?

☐ ☐ 5. Do you have a bone or joint problem (ex. back, knee or hip) that could be made worse by a change in your physical activity?

☐ ☐ 6. Is your doctor currently prescribing drugs (ex. water pills) for your blood pressure or heart condition?

☐ ☐ 7. Do you know of any other reason why you should not do physical activity?

Supplementary Questions:

☐ ☐ 1. Have you ever had knee surgery or a knee injury?

☐ ☐ 2. Do you have a history of blood clots?

☐ ☐ 3. Do you have any neurological diseases?

Medical History: the subsequent sections were obtained following guidelines for exercise testing (American College of Sports Medicine, 2005).

A. History: please check the box any condition you currently have or had in the past.

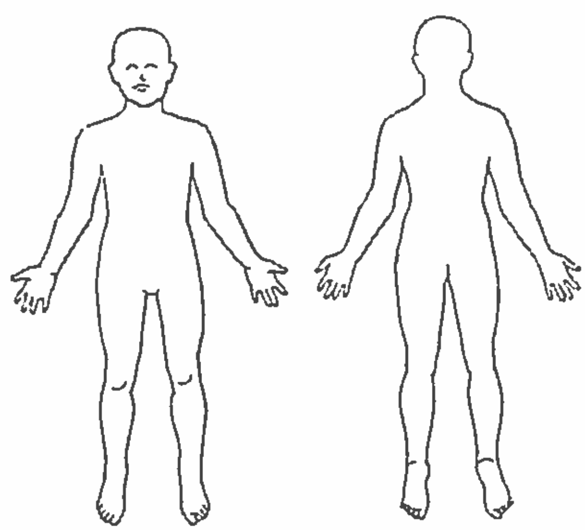
- ☐ Heart Attack
- ☐ Heart Surgery
- ☐ Cardiac Catheterization
- ☐ Coronary Angioplasty (PTCA)
- ☐ Pacemaker/implantable cardiac
- ☐ Defibrillator/rhythm disturbance
- ☐ Heart valve disease
- ☐ Heart failure
- ☐ Heart transplantation
- ☐ Congenital heart disease
- ☐ Diabetes
- ☐ Asthma
- ☐ Lung Disease
- ☐ Heart murmur
- ☐ Seizures
- ☐ Head injury or concussion
- ☐ Loss of consciousness or memory

B. Symptoms: please check the box for any symptoms you have or had experienced at rest, during or following exercise.

- ☐ Chest discomfort
- ☐ Cough or wheezing
- ☐ Dizziness, fainting, or blackouts
- ☐ Difficulty breathing
- ☐ Abnormal heart beats

Musculoskeletal Symptoms: please check the box for any symptoms you have or had experienced, locate and label the occurrence of each symptom on the figure below.

- ☐ Numbness
- ☐ Tingling
- ☐ Pain
- ☐ Swelling
- ☐ Burning
- ☐ Cramping



C. Cardiovascular Health: please check the box for any conditions applicable to you.

- ☐ Male over age 45 years
- ☐ Female over age 55 years
- ☐ Smoke or smoking cessation within the previous 6 months
- ☐ High blood pressure (greater than 140/90 mm Hg)
- ☐ Currently taking blood pressure medication
- ☐ High cholesterol (greater than 200 mg/dL)
- ☐ Family history of heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister)
- ☐ Physically inactive (less than 30 minutes of physical activity at least 3 days per week).
- ☐ Overweight

D. Additional Questions: please identify any additional health issues by checking the corresponding boxes to answer "yes" or "no."

	Yes	No
1. Have you had a medical illness or injury since your check up or last physical?	☐	☐
2. Do you have an ongoing chronic illness?	☐	☐
3. Are you currently taking any prescription or nonprescription (over the counter) medications or pills or using an inhaler?	☐	☐
4. Has a physician ever denied or restricted your participation sports for any heart problems?	☐	☐

Explain all "Yes" answers here and any checked boxes: ____

____

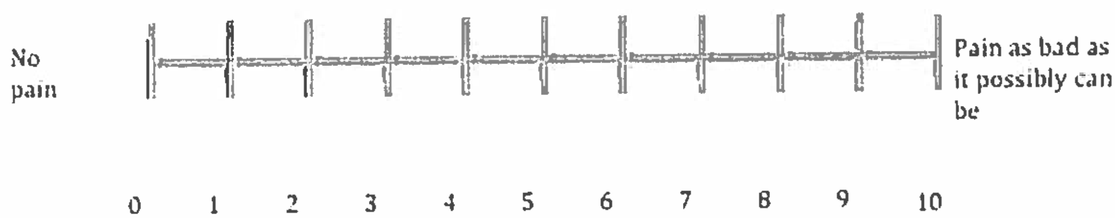
Signature of Participant: __________________________ Date: _______________

Date_____________ Participant #____________

Appendix: E
Visual Analog Pain Scale

Upon determining maximum stimulation intensity by NMES device you will be asked to gauge the amount of pain you are experiencing. Mark a point on the line below representing the amount of pain you are experiencing. The left side of the line represents feeling no pain, while the far right represents you are experiencing the greatest amount of pain. If at any point you are feeling any pain the electrical stimulation will be terminated.

How severe is the pain you are experiencing?



Participant ID: ____

Appendix: F
Electrical Stimulation Intensity (DC)

Date __/__/__

Time __: __ am/pm

Investigator Initials ____

Session:

"The intensity will be increased slowly until you request that it be stopped. Initially you will feel a "tingling" sensation. The sensation should be strong, but should not cause any pain."

Source of Electrical Stimulation: Direct Current Stimulator

Set	Intensity Achieved	Visual Analog Pain Scale Rating/ Comments
1		
2		
3		

Participant ID: ____

Appendix: G
Electrical Stimulation Intensity (AC)

Date __/__/__

Time __: __ am/pm

Investigator Initials ____

Session:

"The intensity will be increased slowly until you request that it be stopped. Initially you will feel a "tingling" sensation. The sensation should be strong, but should not cause any pain."

Source of Electrical Stimulation: Alternating Current Stimulator

Set	Intensity Achieved	Visual Analog Pain Scale Rating/ Comments
1		
2		
3		

Appendix: H
Biodex Positioning Form

Biodex Positioning	
Administrator Initial	

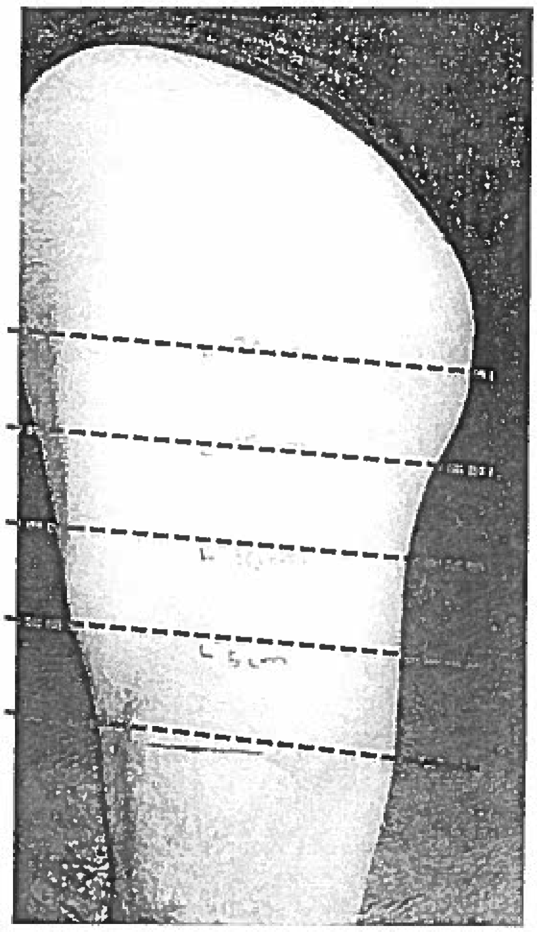
Participants ID	
Date	
Time	

RIGHT KNEE EXTENSION	
CHAIR HEIGHT	
CHAIR ROTATION	
CHAIR SLIDE	
SEAT BACK TILT	90°
SEAT SLIDE	
DYNA SLIDE	
DYNA TILT	0°
DYNA HEIGHT	
DYNA ROTATION	
SHIN EXTENSION	
CUSHION SOFTNESS	6

Appendix: I
Stimulation Intensity Script

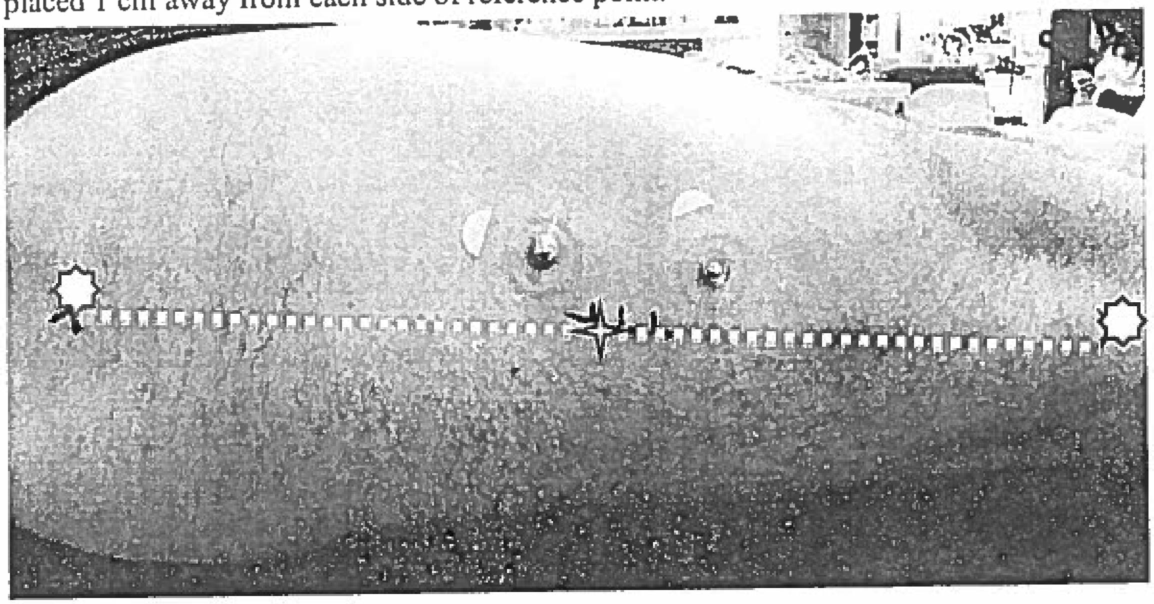
"The intensity will be increased slowly until you request that it be stopped. Initially you will feel a tingling (similar to leg regaining feeling after paresthesia or numbness) sensation, the sensation should be strong, but should not cause any pain."

Appendix: J
Thigh Girth Measurement



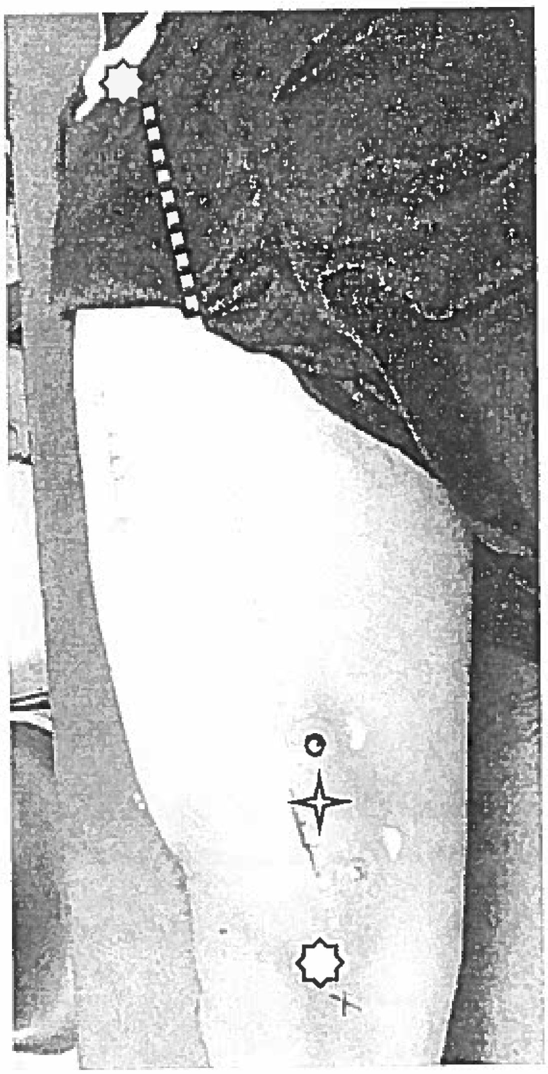
Appendix: K
Integrated Electromyography Electrode Placement

Electromyography Electrode Placement for Vastus Lateralis Greater Trochanter (Proximal) measured to lateral femoral epicondyle (Distal), 50% of the measured length is the reference point (Indicated as star on diagram), positive and negative electrode placed 1 cm away from each side of reference point.

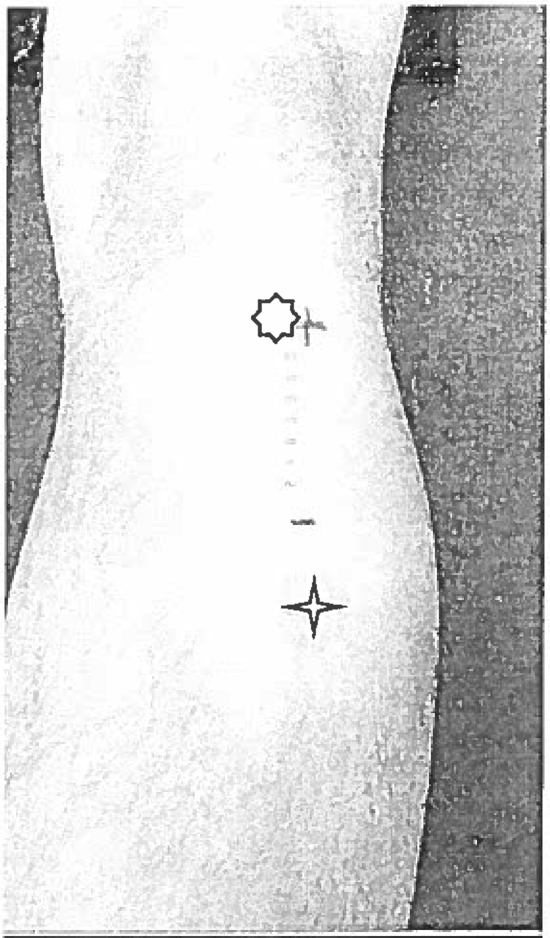


Electromyography Electrode Placement for Rectus Femoris Anterior Superior Iliac Spine (Proximal) measured to superior pole of patella (Distal), 50% of that length is the reference point (Indicated as star on diagram), positive and negative electrode placed 1 cm above and below reference point.

Electromyography Electrode Placement for Vastus Medialis
Anterior Superior Iliac Spine (Proximal) measured to medial joint line (Distal), 80% of that length is the reference point (Indicated as star on diagram), positive and negative electrode placed 1 cm above and below reference point.

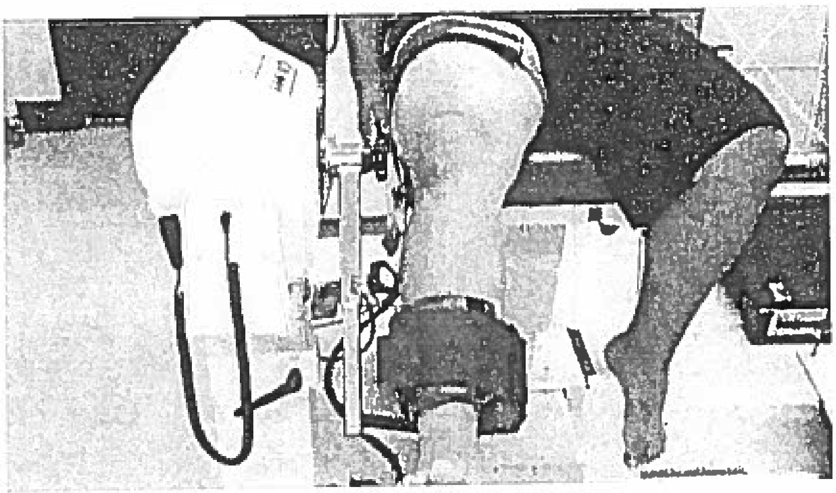


Electromyography Electrode Placement for Ground Electrode Reference point is 6 cm below the tibial tuberosity. Ground electrode is placed beneath reference point.



Appendix: L

Biodex Isometric Testing/ Training Performed at 60 Degrees of Knee Extension



Appendix: M
Thigh Girth Intraclass/ Interclass Correlation

Thigh Girth: Interaclass Correlation			
MEASURMENT ICC	INTER-RELIABILITY	INTRA-RELIABILITY RATER A	INTRA-RELIABILITY RATER B
5 cm	0.966	0.987	0.997
SEM	0.567	0.364	0.162
5 cm C	0.959	0.990	0.993
SEM	0.605	0.339	0.229
10 cm	0.987	0.992	0.996
SEM	0.391	0.303	0.221
10 cm C	0.990	0.996	0.997
SEM	0.359	0.227	0.198
15 cm	0.992	0.996	0.996
SEM	0.349	0.250	0.246
15 cm C	0.996	0.997	0.998
SEM	0.249	0.219	0.174
20 cm	0.991	0.997	0.997
SEM	0.370	0.217	0.212
20 cm C	0.992	0.998	0.998
SEM	0.345	0.178	0.168
ICC: Intraclass Correlation Coefficient SEM: Standard Error of Mean (Centimeters) cm: centimeters C: contracted			

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RAW DATA

Maximum Voluntary Isometric Contraction at 60 Degrees Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	45331.62	1.409	32182.94	43.607	0.000
Time * Treatment	397.273	2.817	141.021	0.191	0.892
Error(time)	28067.519	38.031	738.014		

Maximum Voluntary Isometric Contraction at 90 Degrees Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	13448.987	2	6724.493	7.08	0.002
Time * Treatment	2211.002	4	552.751	0.582	0.677
Error(time)	51286.404	54	949.748		

Mean Rectus Femoris Integrated Electromyography at 60 Degrees Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	0.338	2	0.169	9.965	0.000
Time * Treatment	0.071	4	0.018	1.041	0.395
Error(time)	0.915	54	0.017		

Peak Rectus Femoris at 60 Degrees Integrated Electromyography Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	1.235	2	0.617	9.043	0.000
Time * Treatment	0.085	4	0.021	0.312	0.869
Error(time)	3.687	54	0.068		

Mean Vastus Medialis Integrated Electromyography at 60 Degrees Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	0.169	2	0.085	5.788	0.005
Time * Treatment	0.088	4	0.022	1.505	0.214
Error(time)	0.788	54	0.015		

Peak Vastus Medials Integrated Electromyography at 60 Degrees Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	0.424	2	0.212	5.368	0.007
Time * Treatment	0.213	4	0.053	1.349	0.264
Error(time)	2.134	54	0.04		

Mean Vastus Lateralis Integrated Electromyography at 60 Degrees Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
time	0.166	2	0.083	24.195	0.000
time * Treatment	0.022	4	0.005	1.6	0.188
Error(time)	0.185	54	0.003		

Peak Vastus Lateralis Integrated Electromyography at 60 Degrees Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	0.364	2	0.182	17.459	0.000
Time * Treatment	0.085	4	0.021	2.026	0.104
Error(time)	0.563	54	0.01		

Mean Vastus Lateralis Integrated Electromyography at 90 Degrees Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	0.134	2	0.067	12.204	0.000
Time * Treatment	0.034	4	0.008	1.533	0.206
Error(time)	0.285	52	0.005		

Peak Vastus Lateralis Integrated Electromyography at 90 Degrees Repeated Measures Analysis of Variance Output

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	0.335	2	0.167	8.858	0.000
Time * Treatment	0.119	4	0.03	1.572	0.196
Error(time)	0.982	52	0.019		

Body Mass One-way Analysis of Variance Output Over Testing Periods

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Body_Mass1	Between Groups	852.748	2	426.374	3.225	.055
	Within Groups	3569.806	27	132.215		
	Total	4422.554	29			
Body_Mass2	Between Groups	704.886	2	352.443	2.634	.090
	Within Groups	3612.615	27	133.801		
	Total	4317.501	29			
Body_Mass3	Between Groups	677.676	2	338.838	2.438	.106
	Within Groups	3752.319	27	138.975		
	Total	4429.995	29			

Height One-way Analysis of Variance Output Over Testing Periods

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Height 1	Between Groups	71.982	2	35.991	.909	.415
	Within Groups	1069.525	27	39.612		
	Total	1141.507	29			
Height 2	Between Groups	67.704	2	33.852	.831	.446
	Within Groups	1099.319	27	40.716		
	Total	1167.023	29			
Height 3	Between Groups	48.608	2	24.304	.597	.558
	Within Groups	1099.680	27	40.729		
	Total	1148.288	29			

ID	Treatment	PRE 5 cm Girth	MID 5 cm Girth	POST 5 cm Girth	PRE 10 cm Girth	MID 10 cm Girth	POST 10 cm Girth	PRE 15 cm Girth	MID 15 cm Girth	POST 15 cm Girth	PRE 20 cm Girth	MID 20 cm Girth	POST 20 cm Girth
1	DC	39.8	39.45	39.05	44.65	43.7	43.75	49.65	48.8	48.35	53.8	52.4	52.2
2	DC	44.25	43.5	43.75	45.6	48.2	48.15	52.45	52.2	52.325	54.65	54.5	55
4	DC	43.5	42.45	43.15	49.1	49.175	49.6	55	54	55.75	58.15	57.7	55.2
10	DC	42.5	42.25	41.65	47.75	47.575	47.25	51.1	51.375	50.8	54.2	54.55	53.35
11	DC	37.7	37.575	37.5	43.15	42.375	42.15	49	47.9	47.625	52.9	52.1	52.5
13	DC	43.65	43.55	43.55	45.5	48.3	45.5	53.1	52.675	52.7	56	55.5	55.9
14	DC	44.125	44.25	43.75	45.05	48.325	47.55	52.05	52.05	51.65	54.6	55.25	54.675
15	DC	40.6	41.7	39.85	45.325	46.125	44.8	49	48.875	48.1	50.55	50.5	51.1
17	DC	51.875	51.375	51.6	57.125	57.1	57.25	61.3	52.1	62.07	64.95	66.3	65.3
22	DC	40.75	42	42.75	46.4	51.6	47.75	50.65	51.5	52.15	54.1	54.5	54.95
3	AC	53.5	52	52.9	59.25	57.6	58.475	63.5	62.25	62.675	55.5	65.2	64.175
5	AC	48.5	49.75	47.75	55.1	56.5	54.6	61	61.95	60.85	64.5	64.55	64.9
9	AC	41	40.35	40.05	46.25	45.2	45	50.9	49.4	49.9	54.2	52.5	53.5
18	AC	40.7	42.2	42.2	44.9	46.3	46.2	48.75	49.25	50	50.55	51.15	52.3
19	AC	38.35	38.65	38.45	42.6	43.9	43.9	48.175	48.8	48.9	51.7	52.3	52.6
21	AC	42.55	43.65	41.75	47.9	48.8	47	52.35	53.2	51.6	54.9	55.05	54.75
24	AC	44.9	43.95	43.9	49.8	48.7	45.7	53.25	51.65	51.9	54.7	53.6	53.85
25	AC	48.7	47.5	47.45	54.1	53.6	53.4	59.5	59.05	58.4	61.8	61.75	60.65
26	AC	44.25	44	43.9	45.9	48.7	49	52.8	52.1	52.25	55.8	55.5	54.8
29	AC	44.7	45	46.55	50.35	50.25	52.35	55.45	55.85	56.9	59.25	59.3	61.1
6	CON	47.6	46.4	47.9	53.65	52.05	53.1	58.3	56.775	57.9	62.35	61	62.4
7	CON	40.65	40.475	40.1	45.1	45.6	45.2	50.75	50.1	49.125	54.5	52.9	53.025
8	CON	48.75	49.575	48.55	54.1	54.525	53.9	56.9	56.9	57.3	59	58.4	58.85
12	CON	52.45	52.35	52.25	55.4	56.2	55.45	59.9	60.5	59.9	64.625	65.55	55.65
20	CON	42.35	44.25	44.1	47.35	51.1	49.55	54.1	55.62	55.65	58.65	59.5	59.9
23	CON	39.5	42.57	42.4	45	48.65	45	51.65	53	53	55.2	56.55	56.45
27	CON	39.45	43	42.8	46.05	49.25	47.95	51.25	54.25	52.85	55	56.2	55.35
30	CON	48.05	48.5	46	54.75	55.45	53.05	59.35	58.7	57.45	61.5	61.1	60.75
31	CON	43.5	43.5	41.25	47.52	47.65	45.45	51.9	52.4	49.9	55.9	55.95	53.1
32	CON	55	54.6	53.2	58.55	58.75	58.25	62.7	52.6	61.9	55.9	65.65	55.2

ID	Treatment	PRE 5 cm Contracted Girth	MID 5 cm Contracted Girth	POST 5 cm Contracted Girth	PRE 10 cm Contracted Girth	MID 10 cm Contracted Girth	POST 10 cm Contracted Girth	PRE 15 cm Contracted Girth	MID 15 cm Contracted Girth	POST 15 cm Contracted Girth	PRE 20 cm Contracted Girth	MID 20 cm Contracted Girth	POST 20 cm Contracted Girth
1	DC	40	39.625	38.65	45.25	44.975	44.125	49.775	48.375	48.775	54	52.75	52.65
2	DC	44.1	43.7	43.3	49.3	48.6	48.25	52.5	52.5	52.65	54.9	54.9	55.4
4	DC	42.15	43.6	43	49.4	49.525	49.8	55	54.85	55	58.75	58.45	58.35
10	DC	42.35	42.6	41.4	47.75	48	47.6	51.4	51.375	51.25	54.575	53.675	54.15
11	DC	37.85	37.45	37.4	43.5	43	42.5	48.5	48	48	53.1	51.9	52.3
13	DC	43.7	43.5	43	49.4	48.95	48.45	53.25	52.25	52.9	56.2	56.1	55.5
14	DC	43.875	44.6	44.5	48.725	46.65	46.675	52.25	52.325	52.15	55	55.575	54.9
15	DC	40.2	40.975	41.1	46.35	45.8	46	49.1	49.2	48.85	51.25	50.8	50.65
17	DC	51.42	51.6	51.65	57.125	57.25	57.4	61.25	61.65	61.9	65.5	66.25	65.15
22	DC	41	42.4	43.1	46.3	47.5	48.2	51	51.9	52.35	54.2	54.8	55.15
3	AC	54.25	52.5	53.6	58.9	58.2	59.375	63	62.75	63	65	65.225	64.45
5	AC	49.2	49.75	46.8	57.75	57.225	56.7	61.9	62.7	61.6	64.5	65.5	65.1
9	AC	41.3	40.25	40.95	46.5	44.875	45.25	50.8	49.675	49.9	54.4	52.625	53.5
18	AC	40.95	42.15	42.2	45.2	46.5	46.2	48.35	49.45	50	50.8	51.35	52.3
19	AC	38.125	38.8	38.7	43.475	44.4	43.3	48.5	48.75	48.7	52.37	52.2	52.35
21	AC	43.05	43.62	42.65	48.3	49.05	46.65	52.65	53.2	52.05	55.7	55	55.5
24	AC	44.45	44.65	44	49.4	48.9	48.85	52.8	51.8	52	54.7	53.75	54.2
25	AC	47.45	48.8	47.75	54.25	54.5	53.65	58.2	58.7	58.3	61.1	61.65	60.95
26	AC	43.9	44.2	43.75	48.95	46.8	48.9	52.4	52.2	52.1	55.5	55.4	55.15
29	AC	44.65	45.15	46.6	50.32	50.7	52.4	55.25	55.4	56.7	59.7	59.25	61
6	CON	47.8	46.5	47.9	54.3	52.6	52.65	60.2	57.225	58.35	63	61.5	62.55
7	CON	40.8	41.15	40.45	46.25	45.95	45.4	50.9	50.5	49.3	54.8	53.45	53.125
8	CON	49.6	49.9	48.9	54.35	54.9	54.2	57.55	58.15	57.3	59.5	59.55	59.1
12	CON	53.1	52.925	52.65	56.5	56.5	56.5	60.9	60.5	60.325	64.9	65.8	65.625
20	CON	41.6	44	44	49.25	49.8	50.3	54.5	54.9	55.8	59.15	59.45	60.3
23	CON	40.5	43	42.3	48.15	49.1	46.9	52.25	53.75	53.15	56.3	56.7	56.5
27	CON	40.8	43.2	43.4	47.7	49.05	48	53.6	54.3	52.85	56.3	55.65	55.7
30	CON	48.2	49.1	47.1	54.85	55.15	54.25	59.35	59.3	58.35	61.35	61.1	61.4
31	CON	44	43.5	40.9	48.35	47.8	46.2	52	52.3	50.2	55.65	56	53.4
32	CON	55.1	55.3	54	59.25	59.1	58.5	64.2	63.1	62	66.1	65.7	66.3

ID	Treatment	PRE MVIC at 60 Deg	MID MVIC at 60 Deg	POST MVIC at 60 Deg	PRE MVIC at 90 Deg	MID MVIC at 90 Deg	POST MVIC at 90 Deg
1	DC	134.75	153.35	184.7	162.6	150.4	152.8
2	DC	183.95	203.4	256	197.25	249.3	202.25
4	DC	155.75	157.9	155.75	205.2	176.1	205.2
10	DC	128.45	171.15	177.8	123.35	159.4	149.15
11	DC	106.55	160.75	168.45	126.85	165.5	171.75
13	DC	123.5	145.5	180.2	138.65	159.2	189.15
14	DC	175.4	172.6	194.55	198.85	207.3	189.7
15	DC	142.65	179.75	170.35	133.55	147	121
17	DC	134.2	218.3	229.65	169.15	177.7	231.6
22	DC	119	151.65	159.55	109.25	127.15	123.6
3	AC	161.65	179.2	253.75	210.9	187.6	244.15
5	AC	180.65	226.7	250.3	214.5	247.3	258.7
9	AC	158.25	195.5	198.9	194.35	201.1	230.65
18	AC	98.75	177.5	184.65	109.4	161.85	153.2
19	AC	118.45	120.75	119.4	96.2	120.6	125.7
21	AC	159.5	174.6	192.2	161.35	159.2	156.45
24	AC	106.5	124.4	120.05	82.55	83.95	86.6
25	AC	183.5	192	194.3	202.8	208.7	188.75
26	AC	150.25	204.2	226.35	126.25	148.6	128.75
29	AC	110.7	218.2	246.8	117.5	218.1	198.95
6	CON	171.5	172.35	218.6	115.9	228.7	254.8
7	CON	132.9	177.7	180.8	171.7	182.9	194.95
8	CON	246.75	286.15	291.1	320.1	289.4	286.4
12	CON	152.9	264.9	302.1	141.85	331.6	159.6
20	CON	196.1	227.6	233.65	224.95	210.35	195.2
23	CON	189.45	251.25	277.85	233.05	265.7	202.85
27	CON	174.25	158.7	174.1	200.1	233.35	240.2
30	CON	180.4	220.7	202.95	225.45	283.5	291.45
31	CON	95.55	115.25	117.45	102.2	99.05	109.55
32	CON	141.7	214.8	264.95	120.3	163.45	237

ID	Treatment	PRE iEMG VM60 Mean	PRE iEMG VM60 Peak	MID iEMG VM60 Mean	MID iEMG VM60 Peak	POST iEMG VM60 Mean	POST iEMG VM60 Peak
1	DC	0.4679515	0.8404295	0.5380755	0.8695355	0.7537665	1.2913565
2	DC	0.383702	0.8478995	0.681893	1.381199	1.1381145	2.1094785
4	DC	0.2533025	0.4760465	0.292726	0.476891	0.29132	0.5694255
10	DC	0.205922	0.4510435	0.2924445	0.5001965	0.358275	0.636798
11	DC	0.1992785	0.4131905	0.2951085	0.553763	0.2912705	0.5757925
13	DC	0.261532	0.478911	0.4897145	0.8197065	0.5044565	1.067787
14	DC	0.4897615	0.979544	0.4262915	0.940109	0.400518	0.7348155
15	DC	0.561915	1.004073	0.672545	1.0322945	0.581375	0.7750835
17	DC	0.193247	0.432199	0.2585025	0.5027025	0.3361205	0.5492635
22	DC	0.2034665	0.388515	0.271324	0.5290735	0.2841505	0.603897
3	AC	0.324062	0.7044685	0.343561	0.634087	0.4231175	0.758609
5	AC	0.518856	1.131533	0.6437285	1.1099645	0.767625	1.547764
9	AC	0.935596	1.165125	0.556373	0.898471	0.352677	0.580415
18	AC	0.244846	0.411502	0.593443	1.023643	0.519725	0.893001
19	AC	0.133479	0.261785	0.203145	0.37565	0.217262	0.404854
21	AC	0.333335	0.648608	0.349826	0.643885	0.207385	0.40782
24	AC	0.28847	0.511374	0.361179	0.58508	0.33288	0.593894
25	AC	0.210974	0.406836	0.261355	0.490542	0.238581	0.387132
26	AC	0.261384	0.460049	0.373871	0.6921475	0.4059915	0.6533075
29	AC	0.1234805	0.27524	0.308496	0.6382955	0.067915	0.108724
6	CON	0.180678	0.315218	0.165481	0.480318	0.313112	0.555286
7	CON	0.25786	0.423387	0.448617	0.70016	0.188856	0.52703
8	CON	0.731773	1.20863	0.450509	0.709933	0.94241	1.56656
12	CON	0.127257	0.234805	0.293639	0.501184	0.335803	0.59605
20	CON	0.353264	0.861378	0.382311	0.675413	0.636512	1.098965
23	CON	0.411765	0.759682	0.567206	1.184107	0.612678	1.12576
27	CON	0.612808	1.1819205	0.666681	1.207818	0.707505	1.360758
30	CON	0.2633915	0.6021135	0.222024	0.419002	0.262964	0.4985205
31	CON	0.0896935	0.159452	0.11606	0.23827	0.126128	0.2348555
32	CON	0.1653295	0.3181535	0.224795	0.4236055	0.3428785	0.567668

ID	Treatment	PRE iEMG RF60 Mean	PRE iEMG RF60 Peak	MID iEMG RF60 Mean	MID iEMG RF60 Peak	POST iEMG RF60 Mean	POST iEMG RF60 Peak
1	DC	0.4563045	0.7441015	0.6023955	1.0531465	0.571965	1.1334945
2	DC	0.4438765	0.820447	0.539686	0.9524725	0.7536615	1.2447045
4	DC	0.5015875	0.8779445	0.4537655	0.9789655	0.5661075	1.22422
10	DC	0.3149195	0.60029	0.638329	1.247556	0.400907	0.688918
11	DC	0.1385005	0.2467515	0.317102	0.5435325	0.367806	0.631378
13	DC	0.236936	0.59352	0.506037	1.1643245	0.4676645	0.878564
14	DC	0.6055115	1.223671	0.430181	0.7902275	0.505298	0.8552795
15	DC	0.652711	0.986975	0.421533	0.777056	0.872513	1.2021035
17	DC	0.260882	0.5715895	0.459274	0.8568675	0.473101	0.8353025
22	DC	0.2037305	0.522013	0.2282545	0.565948	0.444178	0.881945
3	AC	0.2880535	0.6074415	0.2740465	0.553598	0.412128	0.7759915
5	AC	0.2569775	0.4365435	0.4197495	1.026687	0.2681455	0.547691
9	AC	0.4586015	0.778003	0.8199385	1.7553485	0.3498715	0.592601
18	AC	0.44187	1.0962325	0.890586	1.168141	0.8565405	2.1975795
19	AC	0.5735795	0.941772	0.5166755	1.094792	0.5090015	0.887508
21	AC	0.444058	0.7316275	0.7109995	1.2226455	0.6123	1.068515
24	AC	0.304274	0.586343	0.6091465	1.259226	0.522683	1.1736455
25	AC	0.400669	0.6704095	0.390323	0.6775485	0.423344	0.707863
26	AC	0.214519	0.503264	0.489826	0.7766745	0.6919725	1.0693715
29	AC	0.27157	0.63998	0.3541515	0.8014655	0.443216	0.8099235
6	CON	0.2255425	0.428713	0.266568	0.913699	0.597936	0.9980495
7	CON	0.3583005	0.6246105	0.8577825	1.885454	0.875305	1.7537565
8	CON	0.9968495	1.714423	0.6113915	1.2549345	0.768886	1.5367345
12	CON	0.117574	0.2332795	0.274293	0.4663675	0.317352	0.581094
20	CON	0.452446	1.053138	0.534421	1.094452	0.507867	0.9274635
23	CON	0.723362	1.364513	0.7823045	1.52738	1.029268	1.854833
27	CON	0.6303525	1.2178515	0.5682565	1.236542	0.6130405	1.087546
30	CON	0.481144	0.8626755	0.3669675	0.7134305	0.3223675	0.732859
31	CON	0.1339755	0.24995	0.1670365	0.390776	0.204932	0.537296
32	CON	0.2911155	0.53049	0.424448	0.7182695	0.5239215	0.873644

ID	Treatment	PRE iEMG VL60 Mean	PRE iEMG VL60 Peak	MID iEMG VL60 Mean	MID iEMG VL60 Peak	POST iEMG VL60 Mean	POST iEMG VL60 Peak
1	DC	0.285577	0.4541375	0.4060325	0.623772	0.4654865	0.7491215
2	DC	0.3633585	0.717524	0.470768	0.7855105	0.7420105	1.3294155
4	DC	0.2224735	0.3674265	0.23429	0.4053305	0.289891	0.5456885
10	DC	0.2430185	0.4821355	0.4061935	0.649161	0.326585	0.53964
11	DC	0.2497885	0.442058	0.505281	1.0157705	0.4911565	0.8526825
13	DC	0.2319315	0.395397	0.364174	0.5839295	0.361113	0.579979
14	DC	0.340769	0.585187	0.492449	0.9219275	0.4336135	0.744761
15	DC	0.325856	0.5050785	0.367103	0.54968	0.3747655	0.5246925
17	DC	0.160292	0.289491	0.2503895	0.411123	0.245406	0.385327
22	DC	0.182718	0.337227	0.2594565	0.4410395	0.3270544	0.5305705
3	AC	0.199239	0.37104	0.191655	0.311465	0.2718345	0.4218025
5	AC	0.2299085	0.4484465	0.452865	0.7486005	0.359449	0.732757
9	AC	0.312185	0.462194	0.4249365	0.651458	0.360495	0.6478415
18	AC	0.2736145	0.4100455	0.378528	0.6632055	0.4380695	0.741803
19	AC	0.233401	0.4561725	0.262899	0.5151915	0.3086055	0.5589795
21	AC	0.2770895	0.460528	0.309573	0.5399455	0.26661	0.4234205
24	AC	0.2071405	0.3328215	0.250316	0.4175635	0.264949	0.437238
25	AC	0.2419655	0.4017285	0.252424	0.46124	0.319718	0.5286145
26	AC	0.1953875	0.301177	0.303249	0.4526875	0.3111645	0.464733
29	AC	0.1280895	0.230048	0.2746745	0.515476	0.2884965	0.500909
6	CON	0.1707945	0.277402	0.120899	0.337107	0.273423	0.4699725
7	CON	0.295306	0.48416	0.3887935	0.581568	0.3343185	0.5093715
8	CON	0.532634	0.942867	0.358113	0.5907815	0.525351	0.9178395
12	CON	0.1145605	0.1920535	0.229239	0.354702	0.2175265	0.3257285
20	CON	0.167729	0.3453225	0.252386	0.455392	0.2635275	0.429981
23	CON	0.23419	0.3467705	0.269616	0.436107	0.3400225	0.5535755
27	CON	0.209333	0.589634	0.399737	0.577966	0.4526485	0.6874195
30	CON	0.228042	0.3984365	0.2364665	0.3900445	0.279497	0.4622575
31	CON	0.1148145	0.1702225	0.145757	0.257555	0.0092255	0.011501
32	CON	0.1015195	0.1718555	0.137551	0.200903	0.14478	0.205851

ID	Treatment	PRE iEMG VM90 Mean	PRE iEMG VM90 Peak	MID iEMG VM90 Mean	MID iEMG VM90 Peak	POST iEMG VM90 Mean	POST iEMG VM90 Peak
1	DC	0.647115	1.15702	0.824182	1.448411	0.877748	1.940933
2	DC	0.615767	1.1795605	1.2466575	2.178598	1.2298275	1.9454355
4	DC	0.321077	0.5865575	0.358119	0.656711	0.382014	0.658695
10	DC	0.2305455	0.4467325	0.3159725	0.5100785	0.347368	0.6178025
11	DC	0.296157	0.6423955	0.4403865	0.9714765	0.3719835	0.6531705
13	DC	0.286946	0.5503685	0.4386975	0.775701	0.4410125	0.8167635
14	DC	0.578722	1.0416	0.548541	1.08925	0.494935	0.8407395
15	DC	0.55576	0.8631895	0.6824165	1.002587	0.574656	0.982127
17	DC	0.1938435	0.3901265	0.2472315	0.4196405	0.409208	0.681052
22	DC	0.2514355	0.4757345	0.27627	0.519333	0.240766	0.4183205
3	AC	0.5165345	1.07081	0.3945315	0.6845005	-7	-7
5	AC	0.536202	1.012374	0.670193	1.1941	0.798729	1.4449935
9	AC	0.6494905	1.077557	0.287887	0.5723425	0.346748	0.5937895
18	AC	0.292761	0.455115	0.775408	1.226221	0.4874945	0.8357505
19	AC	0.0879315	0.160106	0.1916615	0.375454	0.1743325	0.3079745
21	AC	0.328941	0.5652655	0.441467	0.734532	0.224877	0.3938665
24	AC	0.3618015	0.5395425	0.362228	0.5580985	0.3926235	0.5951465
25	AC	0.1591845	0.3425525	0.2593095	0.4042315	0.226612	0.388542
26	AC	0.263042	0.6495035	0.363442	0.5936525	0.3010705	0.4924365
29	AC	0.2042225	0.385244	0.4342965	0.812915	0.3896175	0.799941
6	CON	0.193383	0.342916	0.3734545	0.758847	0.3760765	0.7081785
7	CON	0.439886	0.709993	0.634307	1.201101	0.00857	0.01124
8	CON	0.2977735	0.76385	0.6447495	1.0561805	1.4595	2.3451395
12	CON	0.156635	0.2652035	0.300635	0.5631105	0.163504	0.28363
20	CON	0.6565345	1.348046	0.3638015	0.6378555	0.413895	0.8595445
23	CON	0.534914	0.892587	0.588188	1.040489	0.5009975	0.8381215
27	CON	0.884564	1.4224525	0.821682	1.537626	0.8331345	1.480265
30	CON	0.3607165	0.665591	0.3578515	0.676471	0.4691325	0.804613
31	CON	0.1546365	0.3049285	0.1429955	0.262182	0.149165	0.3023615
32	CON	0.2433865	0.457583	0.2506205	0.4354475	0.3740675	0.6253525

ID	Treatment	PRE iEMG RF90 Mean	PRE iEMG RF90 Peak	MID iEMG RF90 Mean	MID iEMG RF90 Peak	POST iEMG RF90 Mean	POST iEMG RF90 Peak
1	DC	0.452929	0.902309	0.6692775	1.174378	0.449878	0.9899265
2	DC	0.40583	0.72677	0.670464	1.1260175	0.848159	1.3281955
4	DC	0.49166	0.8780565	0.382049	0.765451	0.6011425	1.061399
10	DC	0.270882	0.5052675	0.6644605	1.2919365	0.344998	0.5907395
11	DC	0.2301655	0.4274745	0.331599	0.5803015	0.4242215	0.711185
13	DC	0.3505935	0.7325755	0.475184	1.1597045	0.3818075	0.651352
14	DC	0.6550875	1.247423	0.340653	0.652591	0.6049115	1.1902875
15	DC	0.6364095	0.9944405	0.0058095	0.0089685	0.5952405	1.023937
17	DC	0.342595	0.6078665	0.4417475	0.778304	0.3802315	0.6241065
22	DC	0.157586	0.4990295	0.1404725	0.496918	0.2140125	0.5427535
3	AC	0.317546	0.592967	0.242631	-7	-7	-7
5	AC	0.234002	0.38824	0.318963	0.6245825	0.210192	0.397582
9	AC	0.412287	0.762395	0.478475	0.9759895	0.272388	0.5244065
18	AC	0.3759265	0.6823135	0.7668565	1.496991	0.833722	1.429191
19	AC	0.408109	0.812514	0.2759005	0.547395	0.4153545	0.8690135
21	AC	0.2617495	0.4579125	0.5794735	1.0729575	0.422568	0.7760435
24	AC	0.3592355	0.649657	0.519424	0.9566095	0.6046615	1.0927785
25	AC	0.377863	0.688057	0.3438215	0.5985405	0.376606	0.626396
26	AC	0.0427015	0.257845	0.427214	0.822268	0.318968	0.620931
29	AC	0.2860405	0.6359615	0.2918985	0.6935565	0.3638755	0.7508355
6	CON	0.3025605	0.5846315	0.406452	0.7844545	0.5584395	1.2045515
7	CON	0.4331555	0.783342	0.6356495	1.3096935	0.689082	1.495194
8	CON	0.6398695	1.121704	0.5880165	0.995501	0.707086	1.299139
12	CON	0.106945	0.188994	0.283823	0.5822635	0.086562	0.1533565
20	CON	0.51979	1.06037	0.3777505	0.829108	0.255536	0.666979
23	CON	0.848981	1.6160645	0.6786285	1.4103125	0.9366325	1.967766
27	CON	0.7963	1.5761725	0.55971	1.049446	0.6239795	1.3116725
30	CON	0.4506205	0.776233	0.447633	0.7117795	0.560333	0.992175
31	CON	0.106909	0.254956	0.1390405	0.3086645	0.1475185	0.3508325
32	CON	0.2941275	0.514283	0.3698425	0.599946	0.4134785	0.6327855

ID	Treatment	PRE iEMG VL90 Mean	PRE iEMG VL90 Peak	MID iEMG VL90 Mean	MID iEMG VL90 Peak	POST iEMG VL90 Mean	POST iEMG VL90 Peak
1	DC	0.3420065	0.5731735	0.484365	0.751395	0.45781	0.9033985
2	DC	0.4749	0.78334	0.7101995	1.1850115	0.680933	1.0305625
4	DC	0.285557	0.493089	0.2809025	0.484759	0.366414	0.5726745
10	DC	0.279294	0.4843395	0.561007	0.8941375	0.3532625	0.554267
11	DC	0.3309705	0.674935	0.662044	1.3024085	0.574671	0.9191635
13	DC	0.2697645	0.5317445	0.3613015	0.5992675	0.3456505	0.5539565
14	DC	0.4379765	0.797464	0.6305285	1.263171	0.6814515	1.211201
15	DC	0.4467565	0.649574	0.3853885	0.5898655	0.3752015	0.5842835
17	DC	0.179685	0.299555	0.276013	0.459605	0.271383	0.479906
22	DC	0.1212915	0.1924605	0.259173	0.3018705	0.314397	0.405226
3	AC	0.23298	0.362911	0.2371485	0.37793	-7	-7
5	AC	0.2321175	0.4283925	0.402511	0.6951165	0.3872465	0.6969865
9	AC	0.3173675	0.507434	0.3864305	0.602353	0.3585455	0.5519825
18	AC	0.305493	0.465755	0.443163	0.702497	0.3813865	0.639261
19	AC	0.1457195	0.2550635	0.2217525	0.367932	0.248552	0.5016625
21	AC	0.4131695	0.70852	0.444862	0.818615	0.312053	0.596377
24	AC	0.270198	0.4378415	0.262123	0.4468815	0.278965	0.4438995
25	AC	0.2455715	0.381876	0.2926495	0.4655275	0.379034	0.6241245
26	AC	0.209068	0.3243485	0.313308	0.5845225	0.261472	0.3983595
29	AC	0.1728425	0.3194535	0.306792	0.509307	0.2812445	0.54341
6	CON	0.18127	0.323019	0.2487355	0.428836	0.3690735	0.6834245
7	CON	0.336224	0.5186745	0.440274	0.757109	0.2291955	0.4360495
8	CON	0.833398	1.466219	0.6184235	0.98069	0.9025025	1.7509385
12	CON	0.140751	0.206025	0.266151	0.4440705	0.1407125	0.2227295
20	CON	0.244604	0.507036	0.229308	0.3726745	0.1892255	0.368513
23	CON	0.230636	0.355884	0.269097	0.429244	0.2834345	0.4730825
27	CON	0.2460195	0.5859395	0.444668	0.711291	0.5575995	0.873652
30	CON	0.309437	0.53698	0.3410675	0.5443355	0.4014485	0.708327
31	CON	0.154435	0.2603545	0.1563035	0.278577	0.0089725	0.0129245
32	CON	0.11433	0.185087	0.1307155	0.195789	0.1375345	0.2124655