THE EFFECTS OF CREATING SUPPLEMENTATION AND THREE DAYS OF ISOKINETIC TRAINING ON MUSCLE STRENGTH, POWER OUTPUT, AND NEUROMUSCULAR FUNCTION

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THE EFFECTS OF CREATINE SUPPLEMENTATION AND THREE DAYS OF
ISOKINETIC TRAINING ON MUSCLE STRENGTH,
POWER OUTPUT, AND NEUROMUSCULAR
FUNCTION

by

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CHAPTER I
INTRODUCTION

It is well known that increases in muscle force production (strength) during the course of a resistance training program occurs as a result of muscle tissue adaptations and/or neurological adaptations (16, 32). Numerous studies have demonstrated training-induced increases in muscle fiber hypertrophy (27, 31, 35) as well as changes in muscle fiber type, demonstrating that type IIb muscle fibers tend to take on the type IIa fiber characteristics (35, 21). Studies have also demonstrated training-induced increases in muscle strength with no concomitant changes in muscle fiber size, which have been attributed to neurological adaptations (2, 11, 25, 28, 33, 34). For example, Moritani and deVries (33) examined the time course of the neurological and hypertrophic factors that contribute to training-induced increases in muscle strength. The authors suggested that the largest portion of the strength increases occurred during the first 3 weeks due to an increased ability to recruit additional motor units, after which time the additional strength gains were largely attributable to muscle hypertrophy (33). What seems to be less understood, however, are the time course and magnitude of these neuromuscular adaptations during the first few strength training sessions.

Recent short-term resistance training studies have reported increases in strength (2, 34, 35) and rate of velocity development (RVD) (9) in as few as only 2 resistance training sessions (9, 34). For example, Prevost et al. (34) examined the effects of slow
(30°·s⁻¹) and fast (270°·s⁻¹) isokinetic resistance training during 2 leg extension training sessions and reported no strength increases for the slow velocity training group, but a significant increase in strength at 270°·s⁻¹ for the fast velocity training group. In addition, Brown and Whitehurst (9) recently replicated the Prevost et al. (34) study and investigated the effects of slow (60°·s⁻¹) and fast (240°·s⁻¹) isokinetic resistance training during 2 leg extension training sessions. The authors reported no training-induced changes in strength for either group (slow or fast) at any velocity, however, there were improvements in RVD for the slow and fast velocity training groups. Akima et al. (2) studied the effects of a 2-week resistance training program (9 training sessions) and reported training-induced increases in muscle strength and muscle activation (via magnetic resonance imaging), but no changes in muscle cross-sectional area or fiber type morphology. Collectively, these studies (2, 9, 34) have demonstrated the capability of rapid neuromuscular adaptations in response to short-term resistance training. Little is known, however, about the mechanisms underlying these rapid adaptations.

Surface electromyography (EMG) and mechanomyography (MMG) have been used as noninvasive methodologies to quantify the neuromuscular motor control strategies that modulate muscle force and power production (14, 17, 19, 20, 37). Surface EMG records the electrical muscle action potentials that pass through the electrode recording areas during a skeletal muscle action, whereas MMG records and quantifies the mechanical lateral oscillations or vibrations of contracting skeletal muscle fibers that radiate to the surface of the skin. It has been suggested that the time domain
(amplitude) of the surface EMG signal is reflective of the number of motor units recruited (4), while the frequency domain may globally reflect the muscle action potential conduction velocity (4, 7) of the activated motor units. For the MMG signal, it has been hypothesized that the time domain may also be directly related to motor unit recruitment (1, 5, 12), but inversely related muscle stiffness (14, 15, 18). The frequency domain of the MMG signal, however, may provide information regarding the average motor unit firing rate (rate coding) (1, 5, 12). Therefore, the use of the time and frequency domains of the surface EMG and MMG signals in the present study may provide unique and useful information regarding the motor control strategies that influence any peripherally modulated neuromuscular adaptations that may occur in response to short-term resistance training.

Oral supplementation of creatine monohydrate has also been shown to increase muscle strength and performance following exercise training (3, 23, 24, 29, 36, 37). Kambis and Pizzedaz (29) showed an increase in mean power output and decrease in time to peak torque in women supplemented with creatine for 5 days, compared to a placebo group. There were no gains in body weight or thigh circumference associated with the enhanced muscle performance following the 5-day treatment phase. Acute creatine ingestion has also been shown to delay the onset of neuromuscular fatigue, as demonstrated by Stout et al. (37). Similarly, Greenhaff et al. (24) showed that with short-term creatine supplementation, subjects were able to maintain a greater torque production during repeated bouts of maximal muscle contractions. It was suggested that this was due to an increased concentration of creatine in the muscle, as well as more
rapid phosphocreatine resynthesis during exercise and recovery. It is possible, therefore, that short-term creatine supplementation, in conjunction with a short-term resistance training program may elicit improvements in muscle strength and power. No previous studies, however, have examined the effects of creatine supplementation on the rapid neuromuscular adaptations that may occur in response to short-term resistance training.

The potential for short-term resistance training and/or creatine supplementation to enhance muscle strength and performance has implications for allied health professionals such as physical and occupational therapists and athletic trainers that work in rehabilitation settings. For instance, it is often common for a patient who is prescribed rehabilitative care to be limited in their ability receive physical rehabilitation treatments, either due to minimal insurance coverage or simply poor compliance, which results in the patient only attending a few rehabilitation visits. If a patient does not demonstrate improvements after only a few visits, they may be at risk for a reoccurrence of the injury. If short-term resistance training and/or creatine supplementation can lead to improved muscle integrity and enhanced muscular performance, it may be enough to increase patient compliance, reduce the risk of re-injury, or in the case of preventative medicine, it may act as a viable alternative for more expensive, invasive procedures such as surgery. However, no previous studies have investigated the effects of short-term resistance training in conjunction with creatine supplementation on muscle performance. Therefore, the purpose of this study is to examine the effects of 3 days of isokinetic resistance training at 150°·s⁻¹ in
conjunction with oral creatine monohydrate supplementation and a placebo on peak
torque (PT), mean power (MP), rate of velocity development (RVD), and the time and
frequency domains of the surface EMG and MMG signals. Based on the literature, it is
hypothesized that there will be: (a) training-induced increases in PT, MP, and RVD,
EMG amplitude, and MMG amplitude that are independent of creatine supplementation
and (b) additional increases in PT, MP, and RVD, above those exhibited by the placebo
group, for subjects who supplement with creatine.

1.1 Definition of Terms

Angle-torque relationship – the curve/relationship created during a maximal, voluntary,
concentric isokinetic muscle action, where joint angle position (°) is the abscissa and
torque production (Nm) is the ordinate; the angle-torque curve is often used as a global,
indirect indicator of the length-tension relationship of the contracting skeletal muscle.

Peak Torque (PT) – the peak torque achieved during a maximal, voluntary, concentric
isokinetic muscle action; the peak of the angle-torque relationship; expressed in
Newton-meters (Nm).

Mean Power Output (MP) – the average power generated during a maximal, voluntary,
concentric isokinetic muscle action; calculated by integrating the area under the angle-
torque relationship (Nm²) and dividing by the time duration of the muscle action (s);
expressed in Watts (W).

Rate of Velocity Development (RVD) – the acceleration of the limb during a maximal,
voluntary, concentric isokinetic muscle action; calculated as the distance (°) necessary
to accelerate the limb from $0° \cdot s^{-1}$ (zero velocity) to the pre-determined angular velocity
(in this study, either 30, 150, or 270°·s⁻¹); there is an inverse relationship between RVD and performance; expressed in degrees (°).

*Surface Electromyography (EMG)* – a recording of the muscle action potentials that sweep across the sarcolemma and pass through the surface electrode recording areas during a skeletal muscle action; contains physiological information in the time domain (amplitude) and the frequency domain (median power frequency; MDF), which may represent motor unit recruitment and muscle action potential conduction velocity, respectively; the raw signal is expressed in microvolts (µV).

*Mechanomyography (MMG)* – a recording of the lateral oscillations produced by contracting skeletal muscle fibers; contains physiological information in the time domain (amplitude) and the frequency domain (MDF), which may represent motor unit recruitment / muscle stiffness and firing rate, respectively; the raw signal is expressed in microvolts (m·s⁻²).

*Isokinetic Muscle Actions* – a skeletal muscle contraction/action where the velocity of movement throughout most of the range of motion (excluding the acceleration and deceleration phases) is maintained at a fixed angular velocity by the dynamometer; an angle-torque relationship/curve is produced for every isokinetic muscle action.

1.2 Delimitations

Thirty-two men between the ages of 19 and 35 years will be recruited for this study. All participants will complete a health history questionnaire and a written statement of informed consent prior to any testing and/or training. To be eligible for inclusion in this study, participants must be physically active, which is defined as 1 – 5
hours per week of structured and/or recreational exercise, but they cannot be competitive athletes. The participants cannot take medications that may interfere with exercise performance during the 9-day study protocol, and they cannot take any nutritional supplements during the course of this study or for at least 3 months prior to their enrollment in this study. Each participant that undergoes the isokinetic training protocol will receive $100, while the participants who volunteer in the control group will receive $50 to complete this study.

1.3 Assumptions

1.3.1. Theoretical Assumptions

1. Subjects will accurately answer the health history questionnaire.

2. Subjects in the CRE group will not discuss their testing, training, or nutritional supplement experiences during the course of the study with anyone in the PLA or CON group. This is a double-blind study; therefore, any discussions among participants may influence their performance, which may also affect the statistical assumption of independence of observations.

3. Subjects will participate in all isokinetic testing and training with their maximal effort during each session.

4. Subjects will come in at the same time of day to perform all training sessions, testing sessions, as well as to drink the treatment drinks.

5. Subjects will not engage in any other experimental trials or in a resistance training program of any kind during the course of the 9-day study.
6. All equipment will be calibrated and functioning properly for all testing and training sessions.

1.3.2 Statistical Assumptions

1. The population, which the sample was drawn from, is normally distributed (i.e., normality).

2. The variability among the samples is approximately equal (i.e., homogeneity of variance). Furthermore, due to the within-subjects variables of this study (time [pre- vs. post-testing] and velocity [30°·s⁻¹ vs. 150°·s⁻¹ vs. 270°·s⁻¹]), we also assume that the correlations among all of the factors of each variable (time and velocity) are approximately equal (i.e., homogeneity of covariance). Together, homogeneity of variance and homogeneity of covariance for the collective assumption of sphericity (also called circularity or compound symmetry).

3. The sample is randomly selected, the treatment groups (CRE, PLA, and CON) are randomly assigned, and the angular velocities (30, 150, and 270°·s⁻¹) are randomly ordered.

4. Due to the between-subjects variable of this study (group [CRE vs. PLA vs. CON]), we assume that the responses of each group are independent of each other (i.e., independence of observations). This is directly related to theoretical assumption 2 above.

5. All data is based on a parametric scale.

1.4 Limitations
1. Subjects will be recruited as students in several departmental courses and will respond to advertisements located only in the Physical Education Building and the Activities Building, therefore, the process of subject selection is not truly random.

2. There is no control group that will undergo the testing and the training, but will not take any supplementation.
CHAPTER II
REVIEW OF LITERATURE

2.1 Short Term Strength Training

2.1.1. Prevost, Nelson, and Maraj (34)

The purpose of this study was to examine the impact of two days of velocity-specific isokinetic training of the leg extensors at slow and fast angular velocities on peak torque at three different speeds. Their hypothesis was that two days of training would not be sufficient to elicit muscular adaptations. Therefore, any improvements could be attributed to neural factors. Eighteen men aged 19-35 years were divided into two training groups. The slow velocity group (SVT) trained at 0.52 rad·s\(^{-1}\), while the fast velocity group (FVT) trained at 4.71 rad·s\(^{-1}\). They tested on days 1, 4, and 11. The first two testing sessions were used as reliability measures. On days 7 and 9, subjects performed the training program consisting of 3 sets of 10 maximal leg extension contractions at the assigned velocities. The velocities tested were 4.71, 2.62, and 0.52 rad·s\(^{-1}\) in order from fastest to slowest. They were instructed to contract maximally three times at each velocity with a minimum of 20 s of rest between contractions and 60 s between each velocity. The results did not show a significant difference (\(p > 0.05\)) between the mean peak torque values obtained during pre-tests 1 and 2, which may have contributed to a high reliability coefficient (\(r = 0.99\)). There were no significant differences (\(p > 0.05\)) between the pre- and post-testing peak torques values for 0.52 and 2.62 rad·s\(^{-1}\), indicating that two days of training did not elicit peak torque changes at 0.52 and 2.62 rad·s\(^{-1}\). There was, however, a 22.1% increase (\(p = 0.05\)) in peak torque
for the FVT group at 4.71 rad·s⁻¹. The authors concluded that two days of isokinetic resistance training at a fast isokinetic velocity (4.71 rad·s⁻¹) can improve peak isokinetic torque production, but only at the specific training velocity. Slow isokinetic resistance training (0.52 rad·s⁻¹), however, did not elicit improvements in torque production at any velocity. The authors speculated that the improvements in torque production at 4.71 rad·s⁻¹ may be attributed to neural adaptations that occur as a result of strength training after 2 training sessions.

This study relates to the present investigation because it examined the relationship between short term isokinetic resistance training and the velocity-specific responses of the leg extensors. The present study will re-examine the hypothesis of Prevost et al. (34), and will include the component of creatine supplementation.

2.1.2. Akima, Takahashi, Kuno et al. (2)

The purpose of this study was to examine the effects of a 2-week isokinetic resistance training program on isometric and isokinetic leg extension strength, muscle use, muscle fiber characteristics, and muscle cross-sectional area of the quadriceps femoris muscles. The authors hypothesized that following the training program, leg extension strength and muscle use would increase. Seven men with an average (± SD) age of 24.1 (± 2.0) years participated in this study. All subjects underwent the same training program consisting of 9 training sessions over a 13-day period. During each session, subjects performed 10 sets of 5 maximal voluntary isokinetic leg extensions with the right leg at 120°·s⁻¹ on an isokinetic dynamometer. This velocity was selected due to its success with strength gains in previous studies (6, 10, 26, 30). Peak torque
was tested before and after the training at 60, 90, 120, 180, 240, and 300°·s⁻¹. Magnetic resonance imaging (MRI), transverse reaction time (T2), and muscle biopsies were also taken during the testing sessions. The results indicated an increase in muscle strength following the training, which was attributed to increases in motor unit recruitment. Peak torque during the isometric and isokinetic leg extensions at almost all velocities showed a significant increase ($p = 0.05$) following the training program. There was no significant difference ($p > 0.05$) in muscle cross-sectional area of the quadriceps femoris muscle following the training program. Therefore, the authors suggested that the increases in peak torque may have been due to neural factors. There was also an increase in the percentage of muscle cross-sectional area of muscle activated after training ($p < 0.05$). There were no significant changes in fiber types or fiber area in the quadriceps femoris muscles following the resistance training program, which suggested that the increases in peak torque were probably not due to fiber type transformation in the muscle. The authors concluded that their data supported the hypothesis that muscle strength increases after a short-term (2-week) isokinetic resistance training program without muscle hypertrophy, which suggested that neural adaptations in the early stages of training may elicit the increases in muscle strength.

This study relates to the present investigation because it examines the adaptations of the quadriceps femoris muscles in response to a short term strength training program. The results of this study suggested that muscular adaptations following a short-term resistance training program was due to neural factors, rather than increases in muscle size.
2.1.3. Brown and Whitehurst (9)

The goal of this study was to quantify the effects of a short term high-velocity, low-resistance training program on muscle strength and rate of velocity development (RVD) in the leg extensor muscles. Thirty men and women participated in this experiment. The testing protocol involved 5 maximal voluntary concentric leg extensions and flexions at 1.04 and 4.18 rad·s⁻¹ with 1 min of rest between velocities. Subjects were randomly assigned to one of three groups: (1) control, (2) fast training (4.18 rad·s⁻¹), or (3) slow training (1.04 rad·s⁻¹). Subjects performed 2 training sessions separated by 2-3 days. The training program consisted of 3 sets of 8 voluntary maximal intensity repetitions at each angular velocity. Following the training program, subjects returned to the lab for the post testing. Statistical analysis revealed a significant interaction (p = 0.05) between velocity and time for the slow and fast velocity training groups, but no interaction was found for the control group. A major result was that the training protocol elicited an increase in the RVD, which might explain some of the neural adaptations observed during the short term resistance training programs. Peak torque, however, did not change as a result of the training at either velocity. The authors concluded that acute limb acceleration (RVD) increased after a short-term isokinetic resistance training program at 1.04 and 4.18 rad·s⁻¹, while force production was unaffected.

The use of RVD in the Brown and Whitehurst (9) study introduced a novel variable that can be used to examine the effects of a short-term resistance training
program. Therefore, the RVD will also be examined in the present study in response to short term isokinetic resistance training with and without creatine supplementation.

2.1.4. Chilibeck, Calder, Sale et al (11)

The purpose of this study was to compare the hypertrophy and strength adaptations to complex and simple resistance exercise training. Background information for this study suggested that there is a delayed hypertrophy response caused by neural adaptations with complex (multi-joint) exercise training when compared with simple (single joint) exercises. Twenty-nine women participated and were assigned to either a training group or a control group. The training group performed the resistance training exercises 2 times per week for 20 weeks. They performed complex exercises that included the bench press and leg press. The simple exercise performed was the arm curl. To ensure overall muscle balance during the training program, the “lat” pulldown, leg extension and flexion, and triceps extension exercises were also included. Subjects performed 5 sets of 6-10 repetitions of the upper body exercises and 5 sets of 10-12 repetitions of the lower body exercises. Training loads were performed between 70 and 90% of their 1 repetition maximum (RM). Strength was measured using a 1 RM test, and lean tissue mass was determined using whole-body scans via a dual-energy X-ray absorptiometry densitometer. All tested measurements were obtained pre-, mid- (at 10 weeks), and post-training for the training group, whereas only pre- and post-measurements were taken in the control group. Results from this study showed an increase in strength for the training group by mid-training in the arm curl, bench press, and leg press exercises. Lean mass was greater in the arms by week 10, but for the trunk
and legs, it was not greater until the post-training measurement. Since strength gains were seen without any significant hypertrophy in the trunk and legs, it was suggested the increases in strength in the lower body may be due to neural adaptations. Muscle hypertrophy and strength increases were observed in the upper body at mid-training. The exercise performed for the arms in this study was a simple (single joint) resistance exercise, compared to the complex (multi-joint) exercises of the trunk and legs. Therefore, it was suggested that the time course of the neural adaptations was longer when training with complex exercises since it may involve several aspects of the nervous system. With simple exercises the authors noted that motor unit activation is near 100% in the untrained state; however, with complex exercises, muscle activation is farther from its maximal potential, thus requiring a long training period to notice an increase. The muscle groups of the trunk and legs also contain a greater number of motor units compared to the muscles of the arm. These findings suggested that resistance training with complex exercises may require a longer time course to realize the neural and hypertrophic adaptations that can occur in response to the training.

The Chilibeck et al (11) study is important, because the present study utilizes a single joint, simple resistance training exercise (leg extensions). Thus, based on the findings of Chilibeck et al. (11), any training-induced neural adaptations may occur relatively rapidly after the initiation of the single joint exercise training program, in comparison to multi-joint,complex exercises.

2.2. Electromyography and Mechanomyography Measurements

2.2.1. Hakkinen, Alen, Kraemer et al. (25)
The purpose of this study was to examine the effects of combined strength and endurance training versus strength training alone on functional and structural neuromuscular adaptations in men during a 21-week training period. Thirty-two men participated in this study, and were randomly assigned to either a strength (S) group or a strength and endurance group (SE). Testing sessions took place in 7-week intervals beginning with a pre-testing measurement at week 0. EMG of the vastus lateralis, muscle cross-sectional area (CSA) of the right quadriceps femoris muscles, and maximal oxygen uptake were recorded during the testing sessions. The strength training protocol occurred twice per week and consisted of 2 exercises for the leg extensor muscles, and 4 - 5 exercises for the other main muscle groups of the body. Resistance (load) was determined as a percentage of their one repetition maximum (1 RM). During the first 7 weeks, resistance was set between 50 and 70% of the 1 RM, for 10 - 15 repetitions and 3 - 4 sets per exercise. During the second 7 weeks, the training loads were increased to 60 - 80% of the 1 RM, and during the last 7 weeks, the resistance for the leg exercises was increased to 70 - 80% of the 1 RM for 3 - 6 repetitions. Eight - 12 repetitions were maintained for all other exercises at 50 - 60% 1 RM for 4 - 6 sets. The endurance training increased from 30 to 45 to 60 min on a cycle ergometer across the 7-week intervals. The results indicated a 26% increase in EMG amplitude for the right vastus lateralis muscle in the S group, which was not significantly different from the SE group. The S group also showed a significant ($p<0.01$) increases in the rate of force development, which was not observed in the SE group. A 22% increase in isometric leg extension force production was also reported for the S group, but not for the SE group.
Based on the increases in EMG amplitude, the authors concluded that the training-induced adaptations in the nervous system may have contributed to the strength developments in both groups. The authors suggested that nervous system adaptations may be related to increases in the number of activated motor units and/or increases in the activated motor unit firing frequency.

The study by Hakkinen et al. (25) demonstrated the use of noninvasive methods, such as surface EMG, to examine the training-induced neural adaptations that likely occur during the initial stages of a strength training program. These results are useful because the present study also utilizes noninvasive methods, including surface EMG and MMG to examine the motor control strategies (i.e. motor unit recruitment and firing rate) that may be adapting in response to resistance training.

2.2.2. Gabriel, Basford, and An (22)

The purpose of this study was to examine the neural activity during the early phases of dynamic muscle training. Mean spike amplitude (MSA) and mean spike frequency (MSF) of the EMG signals were evaluated during a maximal voluntary contraction (MVC) at the maximal rate of torque development ($\frac{dt}{dt_{\text{max}}}$). Investigators also sought to examine the relationship between MSF and mean power frequency (MPF) during isometric contractions where the electromyographic (EMG) signal is stationary. Thirteen right-handed women participated in this experiment. The training program consisted of 2-week intervals with 3 sessions of isometric resistance training. During each session, subjects performed 5 maximal voluntary forearm flexion muscle actions, followed by a 24-s rest period. Following a 5-min rest period, they underwent a
fatigue regimen of thirty 2-sec maximal voluntary isometric contractions with 6 s of rest between contractions. Results from this study showed that maximal voluntary isometric forearm flexion torque did not change following the training program. However, \( \frac{dt}{dt_{max}} \) significantly increased \((p<0.05)\) as a result of the training, which was associated with an increase in MSF. The mean MSF and MPF were not different between sessions. The authors summarized that the short-term training protocol was sufficient to increase the rate of torque development and MSF, but not in MSA. Thus, these results suggested that the change in \( \frac{dt}{dt_{max}} \) was due to an increase in rate coding alone.

This study provided unique information regarding the motor control strategies that may be responsible for the adaptations to a short-term resistance training program. Since the present study will use surface EMG and MMG measures, we will be able to noninvasively examine the contributions of muscle activation (motor unit recruitment, EMG, and MMG amplitude) and rate coding (motor unit firing rate; MMG frequency) to any neural adaptations that may occur in response to the resistance training program.

2.2.3. Evetovich, Housh, Weir et al. (19)

The purpose of this study was to examine the effects of concentric isokinetic leg extension training on the mean power frequency (MPF) of the mechanomyographic (MMG) signal. Twenty-one men participated in this investigation and were randomly assigned to 2 groups: (a) training (TRN) and (b) the control (CTL). The TRN group underwent 12 weeks of unilateral concentric isokinetic training of the quadriceps femoris muscles with 3 training sessions per week. Each session consisted of 10 repetitions of maximal concentric isokinetic muscle actions at \( 90^\circ \cdot s^{-1} \) with 2 min rest
between sets. The number of sets increased during the training program from 3 in week 1, 4 in week 2, 5 sets in week 3, and finally 6 sets for weeks 4-12. The testing protocol was performed before the start of training, and every 4 weeks of training. At testing, peak torque was determined for the quadriceps femoris at 90 °·s⁻¹. MMG signals were recorded from the vastus lateralis muscle. The results of the study indicated a significant increase (p<0.05) in peak torque for the TRN group between pre-training and 8 and 12 weeks post-training, however, there was no change in MMG amplitude. The authors suggested that the lack of change in MMG amplitude could be due to the competing influences of muscle hypertrophy and muscle activation as a result of training. Another possible explanation may be related to possible training adaptations that may have occurred in the synergistic and agonistic muscles that contributed to leg extension force production, which may have interfered with the MMG signal of the vastus lateralis.

These results of this study pertain to the present investigation because MMG of the vastus lateralis was used to examine the training-induced changes in muscle strength.

2.2.4. Evetovich, Housh, Housh et al. (20)

The purpose of this investigation was to study the effects of unilateral concentric isokinetic leg extension training on peak torque (PT) and surface EMG responses in the trained and untrained limbs. Twenty men with a mean age of 22 years participated and were randomly assigned to either a training or control group. The training program was the same as the previously reviewed study by Evetovich et al. (19), which included 12 weeks of concentric only isokinetic leg extension training.
Training was performed 3 times a week at an angular velocity of $90^\circ \cdot \text{s}^{-1}$, with the number of sets increasing as the training program progressed. Peak torque and the EMG amplitude of the vastus lateralis was tested prior to training and at 4 week intervals throughout the 12 weeks. A 15.5% increase in peak torque was observed over the 12-week training period. There were no changes, however, in EMG amplitude due to training. Proposed hypotheses for the peak torque and EMG responses observed in the present study included: (1) changes in the neural drive to other muscles or muscle groups involved in the leg extension muscle actions, and (2) muscle adaptations resulting from strength training that may be independent of EMG activity, but influences strength, such as muscle hypertrophy and muscle fiber type conversions from Type IIb to Type IIa.

The results of this study relate to the focus of the present study in that it evaluates the relationship between peak torque and EMG responses during a strength training program involving the vastus lateralis muscle. Peak torque and EMG amplitude are variables targeted in the present investigation to examine the effects of a short-term strength training program.

2.2.5. Cramer, Housh, Evetovich et al. (13)

The purpose of this investigation was to examine the relationship among isokinetic angular velocity, peak torque (PT), mean power output (MP), MMG amplitude, and EMG amplitude of the vastus lateralis muscle during maximal, eccentric isokinetic muscle actions at 30, 90, and $150^\circ \cdot \text{s}^{-1}$. Eight women and 7 men with a mean age of 23 years participated in this study. PT, MP, MMG amplitude, and EMG
amplitude were measured from the vastus lateralis of the dominant leg during maximal eccentric isokinetic leg extension muscle actions. There were no velocity-related changes in PT observed. There were, however, velocity-related increases in MP in both genders. Likewise, there was an increase in MMG amplitude with increasing angular velocities. EMG amplitude, similar to PT, remained unchanged across velocities. The authors suggested that as velocity increased, the actin-myosin bindings were pulled apart more quickly, which would cause an increase in vibration of the muscle, thus increasing the MMG amplitude. It was also suggested that EMG amplitude generally tracked torque production, while MMG amplitude tracked muscle power output.

This study is important to the present investigation because it provides information regarding the velocity-specific patterns of EMG and MMG amplitudes. Since multiple angular velocities will be examined in the present study, it is crucial to understand the velocity-specific relationships of these noninvasive methodologies.

2.2.6. Ebersole, Housh, Johnson et al. (17)

The purpose of this investigation was to study the effects of unilateral, isometric resistance training of the forearm flexor muscles on strength, EMG, and MMG responses in the trained and untrained limbs. The main research questions were: (1) does isometric strength training result in improvements in strength in the trained limb, and (2) are the strength gains a result of mechanical (MMG) or electrical (EMG) adaptations. Seventeen women with a mean age of 21 years participated in this study and were randomly assigned to either a training or control group. The testing protocol consisted of isometric muscle actions of the dominant and nondominant forearm flexors
at 30, 60, and 90° above the horizontal plane. Subjects began with a warm-up of 2 submaximal trials. This was followed by two 4s maximal voluntary contractions (MVC) at each joint angle. The greatest torque at each angle was used as the MVC. Subjects continued with two 4s submaximal muscle actions at 25, 50, and 75% MVC. Both groups were retested with the same protocol after 4 and 8 weeks. The training group underwent 8 weeks of isometric training of the nondominant forearm flexors. Subjects trained 3 times per week with at least 1 day separating training sessions. Training sessions consisted of isometric muscle actions at 80% MVC at a joint angle of 60°. The number of sets performed increased each week starting at 3 for the first 2 weeks, then 4 during weeks 3 - 4, and finally, 5 sets for weeks 5 - 8. Each set included eight 6s muscle actions with 30s rest between contractions. Two minutes of rest were allowed between sets. The data obtained showed an increase in arm circumference in the trained limb by 2.2% after the 8 weeks of training. There was also an increase in strength observed in the trained limb, suggesting muscle hypertrophy of the biceps brachii surrounding agonistic and synergistic muscles. Torque values increased 22.5% at 60°, 32.7% at 30°, and 7.5% at 90°. Since torque values increased at all joint angles, the data did not support the joint angle specificity concept. There was no change in the untrained limb following the 8 weeks. There was no change in MMG amplitude after 8 weeks, despite the increase in torque production. The authors suggested this lack of change in MMG may be due to the influences of hypertrophy on the MMG signal, or the decreased coactivation of the forearm extensor muscles. There were also no changes in EMG signals following the 8 weeks. It was suggested that this lack of EMG amplitude change
may be due to enlarged cross-sectional area of the muscle fibers, thereby altering the positions of the EMG electrodes. This study concluded that strength training of the biceps brachii at 80% MVC resulted in a significant increase in circumference and strength at 3 joint angles. This increase in strength was not accompanied by any change in EMG or MMG amplitude.

This reviewed study relates to the present investigation by providing information on the EMG and MMG responses to isometric training. This study focused on the biceps brachii, whereas the present study will examine similar effects of the vastus lateralis muscle.

2.3 Effects of Short Term Creatine Supplementation

2.3.1. Ayoama and Sasaki (3)

The purpose of this experiment was to examine the effects of creatine supplementation on muscle strength and endurance in women. The investigators also examined the effects of 1 week of anaerobic exercise before starting supplementation, and the disappearance of supplement-related adaptations following the supplementation phase. Twenty-six women with 4-10 years of competitive softball experience were separated into 4 groups, which involved a 4-week program: Two creatine (Cr1 and Cr2) and two control groups (Cont.1 and Cont.2). Cr1 did not engage in exercise during the four week period, and was supplemented with 20 g Cr·d$^{-1}$ during week 2 with a placebo for the remainder of the study. Cr2 performed exercise during the first week, supplemented with 20 g Cr·d$^{-1}$ for week 2, and supplemented with 3 g Cr·d$^{-1}$ for the remainder of the study. Cont.1 did not perform exercise for week 1 and received a
placebo for the remaining three weeks. Cont.2 exercised in week one and a received a placebo for the remaining three weeks. Week 1 was used to examine the effects of exercise on muscular adaptations, without the added supplementation. Leg extension testing occurred at the beginning of the study and at the end of each week. Testing protocols involved 2 maximal voluntary isometric contractions and 30 maximal isokinetic contractions at 180 and 60°·s⁻¹, separated by 20 minutes of rest. The groups that engaged in exercise performed 3 sets of 12 resistance exercises with 10 maximal repetitions or 30 maximal 10 second cycling bouts with 0.1 kg·kg BW⁻¹ as resistance.

The first main result of the study was that creatine supplementation for the women did not elicit an increase in maximal isometric strength or peak torque at the start of 10 isokinetic leg extensions at 60°·s⁻¹. Supplementation did, however, reduce the percent decline of mean torque and increase the mean torque for the final 20 contractions at 180°·s⁻¹. A second finding was that the significant differences in mean torque existing in the first measurement disappeared at the second measurement for the Cr1 group. A final conclusion from this study was that mean torque of the first ten contractions at 60°·s⁻¹ was significantly lower in the third measurement compared to measurement one. In the Cr1 group, the maximal peak torque at the same velocity was significantly decreased in the fourth measurement compared to the previous three measurements. These values were also significantly different in the creatine groups compared to control groups. The three main results indicated that the positive effects of creatine supplementation on muscular performance disappeared one week after the end of supplementation, and negative effects began to appear after two weeks. The authors
concluded that 20 g·d⁻¹ of creatine supplementation for seven days did not improve muscle strength or peak torque, but did improve muscular endurance during repeated contractions performed. Furthermore, the effects of creatine supplementation were enhanced when subjects performed a seven day anaerobic exercise training program before creatine supplementation. The positive effects disappeared one week after the supplementation was ceased.

This study relates to the present investigation by providing information on the performance effects of a short-term creatine supplementation in conjunction with exercise training.

2.3.2. Gilliam, Hohzorn, Martin et al. (23)

The purpose of this study was to examine the efficacy of creatine supplementation on quadriceps femoris fatigue and the recovery of quadriceps femoris function. Twenty-three physically active men between the ages of 20 and 36 years participated. Exercise tests were performed pre- and post-supplementation of either creatine or a placebo. Subjects were familiarized on the isokinetic dynamometer with maximal voluntary contractions of the leg extensors and flexors. The pre-test was performed 4 to 5 days following the familiarization trial. The post-test was performed following a 5-day supplementation period. Testing sessions consisted of 5 sets of 30 maximal contractions with 1 minute of rest between sets. The creatine group supplemented with 5 g creatine and 1 g glucose, where the placebo group supplemented with 6 g glucose. Each group took their respected supplements 4 times a day for 5 consecutive days. Peak torque results indicated a significant 3% increase from pre- to
post-testing for both supplementation groups ($p<0.04$). There was no difference between the groups ($p>0.05$). There was, however, a set effect, with each successive set declining in torque values. Authors concluded that 5 days of creatine supplementation did not have an effect on the maintenance of peak isokinetic torque. Creatine supplementation also did not reduce the loss of torque across subsequent sets, therefore failing to attenuate quadriceps femoris muscle fatigue.

The results of this investigation provide information on the effects of short term creatine supplementation on the function of the quadriceps femoris muscle. The present study will investigate the effects of short term creatine supplementation in combination with short term strength training.

2.3.3. Kambis and Pizzedaz (29)

The goal of this investigation was to examine the effect of creatine supplementation on maximal voluntary concentric contractions of the quadriceps femoris muscles in women. The authors hypothesized that 0.5 g/kg of fat-free mass of creatine supplementation for 5 days would improve muscle function. Twenty-two women with a mean ($\pm$ SD) age of 20.3 $\pm$ 0.2 years participated. Subjects were assigned to groups according to their dietary and exercise habits, menstrual cycle phase, and fat-free mass. Each group contained subjects in the follicular as well as luteal phase of their menstrual cycle. Subjects supplemented 4 times a day for the 5-day period with either creatine or a placebo. They drank their assigned supplement with 250 ml of orange juice at 8am, 12 noon, 4pm, and 8pm each day. Testing took place prior to supplementation and 6 days following the supplementation period. The testing protocol consisted of 5
maximal voluntary contractions at $60^\circ \cdot s^{-1}$. This was followed by a 5-min rest period, and 50 consecutive maximal contractions at $180^\circ \cdot s^{-1}$. The data indicated that creatine supplementation increased ($p=0.05$) the average power output during the extension phase of the 50 repetition trial. There were no differences observed for average power in the placebo group. Time to peak torque in the 50 repetition test for the extensor muscles was decreased ($p=0.05$) in the creatine group only. The results of the study supported the original hypothesis that creatine supplementation would enhance quadriceps femoris muscle function in women. The authors concluded that 5 days of 0.5g per kg of fat-free mass of creatine supplementation improved muscle performance without gains in body weight or thigh circumference. There were also no negative effects reported with the creating supplementation during this study, suggesting short term creatine supplementation may be safe and effective method of improving muscle function.

The results of this study provided useful information regarding short-term creatine supplementation on muscle power and time to peak torque of the leg extensor muscles. Furthermore, the data provided by Kambis and Pizzedaz (29) provided a rationale for investigating the rate of velocity development and muscle power output in conjunction with peak torque, EMG and MMG.

2.3.4. Stevenson and Dudley (36)

The purpose of the study was to examine the effects of creatine loading on fatigue, dynamic constant external resistance (DCER) exercise performance, and one repetition maximum (1 RM) of a leg extension exercise. Tests were performed during
voluntary muscle actions, as well as during contractions elicited by electromyostimulation (EMS) to remove any potential central nervous system influences. Twenty-nine men and 2 women participated in this experiment. They were randomly assigned to either a creatine or placebo supplementation group. Maximal voluntary contraction (MVC), contractile properties during EMS, and dynamic muscle strength and endurance were tested before and after the supplementation period. Testing protocols consisted of 5 MVCs followed by 5 isometric contractions during EMS for each leg. Subjects supplemented with either 5 g of creatine or 5 g of a placebo, 4 times a day for 1 week. There were no time by condition interactions for any tested variable with creatine loading in the leg extensor muscles. The same results were observed when contractions were evoked by EMS. Authors concluded that creatine loading did not enhance performance of unilateral, dynamic leg extensions. In addition, maximal voluntary and EMS evoked contractions were not affected by creatine loading in this investigation.

This study pertains to the current investigation by providing information related to creatine loading on muscle performance and strength of the leg extensor muscles during dynamic muscle actions, which will be examined in the present study.

2.3.5. Stout, Eckerson, Ebersole et al. (37)

The purpose of this investigation was to determine the effect of creatine loading on the onset of neuromuscular fatigue (NMF). NMF was measured using the physical working capacity at the fatigue threshold (PWC_{FT}) test. Subjects included fifteen women that were members of a Division I university rowing team with a mean age (±
SD) of 19.0 (± 2.0) years. They were randomly assigned to one of two groups: (a) the creatine group supplemented with 5 g of creatine monohydrate plus 20 g of dextrose and (b) the placebo group was treated with 20 g of a dextrose powder. Supplements were taken 4 times a day for 5 consecutive days. $\text{PWC}_{FT}$ was determined from the vastus lateralis muscle on an electronically braked cycle ergometer. Power output was increased by 30 W every 2 min until the subject could not maintain a 70 rpm cadence. Electromyographic (EMG) samples were recorded at 2-min intervals during the test. $\text{PWC}_{FT}$ was determined as the average of the highest power output resulting in a nonsignificant slope value for the EMG amplitude vs. time relationship and the lowest power output resulting in a significant slope. The results indicated that creatine supplementation elicited a delay in the onset of NMF. The authors suggested that this may be due to the elevated muscle creatine in the transition from aerobic to anaerobic metabolism. Creatine loading also delayed the fatigue-induced increase in EMG at submaximal power outputs. In conclusion, creatine loading lead to a significantly greater $\text{PWC}_{FT}$ values, which indicated a delayed onset of muscle fatigue.

This study relates to the present investigation due to its examination of creatine loading on neuromuscular function. This study related creating supplementation with EMG responses, which will also be examined in the present study.

2.3.6. Greenhaff, Casey, Short et al. (24)

The purpose of this study was to examine the effects of creatine supplementation on torque production during repeated repetitions of high-intensity exercise. Twelve subjects participated in this study. The exercise protocol consisted of 5
sets of 30 maximal voluntary leg extensions at a constant velocity of \(180^\circ \cdot s^{-1}\). Following pre-testing measurements, subjects consumed either 5 g of creatine plus 1 g of glucose or 6 g of placebo, 4 times a day, for a total of 5 consecutive days. Subjects then came back to perform the same exercise protocol. Arterialized-venous blood samples were collected during the exercise protocol at 4 min post warm-up, 30 s after each set, immediately after the completion of all sets, and at minutes 2, 5, and 10 of recovery following all exercise. Blood samples were used to determine plasma ammonia. The main result of this study was that the subjects receiving creatine supplementation were able to maintain higher peak isokinetic torque values during the repeated contractions. The plasma ammonia was also significantly less in the creatine group compared to placebo. The authors suggested the improved performance seen with creatine supplementation may be caused by the increase in the rate of phosphocreatine resynthesis during exercise and recovery due to the elevated muscle creatine concentration. It was concluded that supplementing with creatine increased total muscle creatine content, thereby reducing the decline in muscle peak torque production during repeated bouts of maximal muscle contractions. The authors suggested that ATP resynthesis was more efficient with supplementation due to the increase availability of phosphocreatine.

This Greenhaff et al (24) study provided useful information regarding short-term creatine supplementation and its effects on torque production during repeated muscle actions. A similar design in the present study will be used to examine changes in muscle strength, power output, rate of velocity development, EMG amplitude, and
frequency, and MMG amplitude and frequency following 3 days of isokinetic resistance training during creatine versus placebo ingestion.
CHAPTER III

METHODS

3.1 Subjects

Thirty-two men between the ages of 19 and 35 years will be recruited for this study. All participants will complete a health history questionnaire and a written statement of informed consent prior to any testing and/or training. To be eligible for inclusion in this study, participants must be physically active, which is defined as 1 – 5 hours per week of structured and/or recreational exercise, but they cannot be competitive athletes. The participants cannot take medications that may interfere with exercise performance during the 9-day study protocol, and they cannot take any nutritional supplements during the course of this study or for at least 3 months prior to their enrollment in this study. Each participant that undergoes the isokinetic training protocol will receive $100, while the participants who volunteer in the control group will receive $50 to complete this study. This study was approved by the University Institutional Review Board for Human Subjects.

3.2 Research Design

This study will incorporate a double-blind, placebo controlled, parallel design. Each participant will be randomly assigned to 1 of 3 groups: (a) treatment (CRE; n = 12), placebo (PLA; n = 12), or control (CON; n = 8). The CRE group will receive the treatment drink, the PLA group will receive an isocaloric placebo drink, and the CON group will receive no supplementation. The CRE group will be asked to consume a
creatine supplement (Phosphagen Elite ®) consisting of 68 g of carbohydrates, 10.5 g of creatine monohydrate, 2 g of taurine, and 2.3 g of β-alanine. The total caloric value of the treatment drink is estimated as 280 kcal. The PLA group will be asked to consume an isocaloric placebo (caloric value equaling the treatment drink; 280 kcal), containing only 70 g of carbohydrates. To administer the supplements, the CRE and PLA group participants will be asked to visit the laboratory 2 times per day (once in the morning and once in the afternoon) for 6 consecutive days (Table 1; Days 1 – 6) and 1 time per day (either morning or afternoon) for 2 additional days (Table 1; Days 7 – 8) to consume their drinks under supervision in the laboratory. The participants will be asked to visit the laboratory at approximately the same time of day (± 2 hrs) for each drink consumption. The CRE and PLA groups will receive 2 servings per day for days 1 – 6 and 1 serving per day for days 7 – 8 (Table 1), and the CON group will receive no supplementation (Table 2).

Table 1.1: Schedule of assessments for the creatine (CRE) and placebo (PLA) groups.

<table>
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<tr>
<th>Procedure</th>
<th>Subject meeting / screening</th>
<th>Test 1</th>
<th>Rest</th>
<th>Train 1</th>
<th>Rest</th>
<th>Train 2</th>
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<th>Train 3</th>
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Table 1.2: Schedule of assessments for the control (CON) group.

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</table>

3.3. Variables

The independent variables will include: (a) group (CRE vs. PLA vs. CON), (b) time (pre- vs. post-training), and (c) isokinetic angular velocity (30°·s⁻¹ vs. 150°·s⁻¹ vs. 270°·s⁻¹). The dependent variables that will be measured during the pre- and post-training isokinetic assessments will include: (a) peak torque (PT), (b) mean power (MP), (c) rate of velocity development (RVD), (d) EMG amplitude, (e) EMG median power frequency (MDF), (f) MMG amplitude, and (g) MMG MDF.

3.4 Strength Testing

Following a 5-min warm-up on a stationary cycle ergometer with the resistance set at 50 W and a pedaling cadence of 60 – 70 rpm, participants will perform 3 maximal, voluntary, concentric isokinetic leg extension muscle actions for the right leg at 3 randomly ordered angular velocities (30, 150, and 270°·s⁻¹) on a Biodex System 3
dynamometer. The participants will be verbally encouraged to produce as much torque as possible during their contractions. The subjects will be in a seated position with restraining straps over the pelvis, trunk, left thigh, and right ankle in accordance with the Biodex User’s Guide (Biodex Pro Manual, Applications/Operations. Biodex Medical Systems, Inc., Shirley, NY.). The input axis of the dynamometer will be aligned with the axis of the knee. Three or 4 submaximal warm-up trials will precede the 3 maximal muscle actions at each velocity, and a 2-min rest period will be allowed between testing at each velocity. Both testing sessions will occur at approximately the same time of day (± 2 hrs) to avoid any potential circadian confounding factors, and all participants (CRE, PLA, and CON groups) will undergo the isokinetic testing on days 1 and 9 (Tables 1 and 2). During each isokinetic testing session, surface EMG and MMG will be measured from the vastus lateralis muscle. The analog signals for torque, position, and velocity will be sampled from the isokinetic dynamometer at 100 points per second, digitized, and stored on a personal computer for off-line analysis. Custom written LabVIEW 7.1 software will be used to determine PT, MP, and RVD for the repetition yielding the highest PT value.

3.5 Training Protocol

After a minimum rest period of 48 hours following the pre-training isokinetic tests, the training groups (CRE and PLA) will perform 3 isokinetic strength training sessions separated by 48 hours on days 3, 5, and 7 (Table 1). The participants in each group will perform 3 sets of 10 maximal, voluntary, concentric isokinetic leg extensions at 150°·s⁻¹. Three or 4 submaximal warm-up trials will precede each set, and a 2-min
rest period will be allowed between each set. All 3 training sessions will occur at approximately the same time of day as the testing sessions (± 2 hrs) to avoid any potential circadian confounding factors. Prior to each training session, each participant will complete a 5-min warm-up on a stationary cycle ergometer with the resistance set at 50 W and a pedaling cadence of 60 – 70 rpm. Although no EMG or MMG signals will be recorded during the training sessions, torque, position, and velocity will be sampled from the isokinetic dynamometer at 100 points per second, digitized, and stored on a personal computer for off-line analysis. Custom written LabVIEW 7.1 software will be used to determine peak torque (PT) for each repetition performed during each set.

3.6 EMG Measurements

A bipolar surface electrode (Moore Medical, Ag-AgCl) arrangement will be placed along the longitudinal axis of the vastus lateralis (VL) muscle of the right leg with a 3.0 cm center-to-center interelectrode distance. With subjects lying in a partially supine position with a slightly flexed knee, the electrodes will be placed over the lateral border of the VL muscle at 66% of the distance of a line extending from the anterior superior iliac spine to the lateral border of the patella. The reference electrode will be placed over the spinous process of the 7\textsuperscript{th} cervical vertebrae. Interelectrode impedance will be maintained below 5,000 Ω by shaving, careful skin abrasion, and cleaning with isopropyl alcohol. The EMG signals will be preamplified (gain = 1000x) using a differential amplifier (EMG100C, Biopac Systems Inc., Santa Barbara, CA; bandwidth =1-500 Hz).
3.7 MMG Measurements

The MMG signal will be measured from the VL muscle using an active miniature accelerometer (EGAS-FS, Entran, Inc., Fairfield, NJ) that will be preamplified (gain = 200x) with an in-line amplifier. The accelerometer will be placed proximal to the active EMG electrodes at 50% of the distance of a line extending from the anterior superior iliac spine to the lateral border of the patella over the VL muscle. The MMG sensor will be fixed to the skin’s surface by 3M double sided foam tape.

3.8 Signal Processing

Using the same Biopac MP150 signal acquisition unit and analog-to-digital converter (Biopac Systems, Santa Barbara, CA) that will be used to sample the torque, position, and velocity signals from the isokinetic dynamometer, the EMG and MMG signals will be sampled at 1000 points per second, digitized, and stored on a personal computer for off-line analysis. All signal processing will be completed using custom written software (LabVIEW 7.1, National Instruments, Austin, TX). First, the EMG and MMG signals will be bandpass filtered with a zero phase shift, 4<sup>th</sup>-order Butterworth filter with bandwidths of 10 – 500 Hz and 5 – 100 Hz, respectively. The PT, MP, EMG and MMG amplitude and frequency values will be calculated for a time period that corresponds to the middle 50° of the leg extension range of motion from approximately 110° to 160° of leg flexion using the position data sampled from the isokinetic dynamometer. For example, at 30°·s<sup>-1</sup>, the middle 1.67 s of the torque, EMG, and MMG signals will be used to calculate the dependent variables. This range of motion was selected for three reasons: (a) to allow comparisons between velocities that
were based on a standardized 50° range of motion, (b) to select an area of the torque signal that occurred during the load range (i.e. constant angular velocity) at 30, 150, and 270°•s⁻¹ (8), and (c) to be consistent with previous recommendations (Iossifidou and Baltzopoulos, 2000) for calculating MP during a constant velocity.

After applying a 10 Hz low-pass filter to the torque signal, PT (Nm) will be calculated as the highest point of the angle-torque curve during the middle 50° range of motion. MP (W) will be calculated as the time-averaged integrated area under the angle-torque curve during the middle 50° range of motion. RVD (°) will be calculated as the range of motion of the lever arm necessary to accelerate from 0°•s⁻¹ (no velocity) to the pre-set, constant angular velocity (8, 9), therefore, any positive training effect would be demonstrated as a decrease in RVD.

The amplitude of the EMG and MMG signals will be expressed as root mean square (RMS) values using the following equation (4, p. 97):

\[
RMS\{m(t)\} = \sqrt{\frac{1}{T} \int_0^T m^2(t) \, dt}
\]

Where \(RMS\{m(t)\}\) is the RMS value of the time domain function \(m(t)\), and \(T\) is the number of sampled points characterizing the time domain epoch. The center frequency of the EMG and MMG signals will be estimated by the median frequency (MDF) function (4, p. 100):

\[
\int_{f_{\text{mid}}}^{\infty} S_m(f) \, df = \int_{f_{\text{mid}}}^{\infty} S_m(f) \, df
\]
Where $S_m(f)$ is the power spectra of the EMG and MMG time domain functions $\{m(t)\}$ with epochs durations = $T$. The power spectra will be defined as (LabVIEW v7.1, Austin, TX):

$$S_m(f) = T \ast (f)T(f) = |T(f)|^2$$

Where $T(f) = F\{m(t)\}$, and $T^*(f)$ is the complex conjugate of $T(f)$. Each EMG and MMG signal epoch will be processed with a Hamming window and Discrete Fourier Transform (DFT) procedure to compute the power spectra, which are given by the following equations (LabVIEW v7.1, Austin, TX):

Hamming window:

$$Y_i = \frac{X_i}{cg} \sum_{k=0}^{m-1} (-1)^k a_k \cos(k\omega)$$

for $i = 0, 1, 2, \ldots, n - 1$

Where $\omega = \frac{2\pi i}{T}$, $m$ is the number of window coefficients, coherent gain ($cg$) is 0.54, the equivalent noise bandwidth is 1.362826, the 6dB bandwidth is 1.82, $a_0 = 0.54$, and $a_1 = 0.46$.

$$S_m = \frac{1}{T^2 |F\{m(t)\}|^2}$$

DFT:

We chose the DFT, as opposed to the Fast Fourier Transform (FFT), because the DFT is not constrained to $2^n$ number of data points (Gniewick, M.T. Waveform analysis using Fourier transform. AT/MCA CODAS Application Note. Dataq Instruments. 1991.). Therefore, DFT analyses were performed without having to truncate the data segments or resort to zero padding.

3.9 Statistical Analyses
Seven separate three-way mixed factorial ANOVAs (time [pre- vs. post-training] x group [CRE vs. PLA vs. CON] x velocity [30°·s\(^{-1}\) vs. 150°·s\(^{-1}\) vs. 270°·s\(^{-1}\)]) will be performed for PT, MP, RVD, EMG amplitude, EMG MDF, MMG amplitude, and MMG MDF. Post-hoc analyses will include lower-order ANOVAs, t-tests, and all pairwise comparisons t-tests with Bonferroni corrections. A type I error rate of 5% (p = 0.05) will be considered the a priori alpha level.
REFERENCES


