**Training distribution and the acquisition of maximal
isometric elbow flexion strength**

by

Kristina M. Calder

Faculty of Applied Health Sciences
Brock University

**A thesis submitted for completion of
Masters of Science Degree**

Kristina M. Calder © 2004

Acknowledgements

How do I even begin to acknowledge all the people who have supported and encouraged me throughout my stint as a Masters student. I suppose I should begin by giving my deepest gratitude to the big man himself, my advisor, Dr. David Gabriel. You have made my time here such an educational and fun experience. I am truly a lucky person to have had the opportunity to work with such a mind—your charisma, humour, ADD, and worldly knowledge will never be forgotten. I would next like to extend my thanks to the entire examining committee Dr. Diane Stevens, Dr. Gail Frost, and Dr. Gary Kamen for all their contributions to my thesis. In particular to Dr. Stevens and Dr. Frost, I would like to thank you for always being available for my last minute lifestyle, your flexibility and support helped make this happen. To Dr. Kamen, the man who knows the best places to eat in Boston, thank you for making the trip out to Canada, it was such an honour to have a researcher of your calibre as my external. To my fellow grad students, what a fantastic two years! Thank you for making my Masters such an unforgettable time, especially to my lab mates Anita, Steve and senior lab scut Greig, thanks for the guidance and assistance. My roommie Les, thanks for being a great friend and putting up with me. And finally, but certainly not last, my family and Steve. Mom and dad, I don't even know where to start with you two, you both have been such an integral and meaningful part of my life. Your constant support (financially & emotionally) let me become the person I am. To my little sis Lisa, you are crazy, but I love you—thanks for always having my back. And to my love, Steven, thank you for always listening and being patient with me over these last two years. Your love has been such a calming factor on the sometimes-chaotic life as a grad student. Thanks everyone. I'll miss you Brock.

ABSTRACT

Twenty-six sedentary, college-aged females were matched and randomly assigned to one of two groups. The massed group ($n=13$) completed 15 maximal isometric elbow flexion strength trials in one session, while the distributed group ($n=13$) performed five such contractions on three successive days. After a two-week and three month rest interval, both groups returned to perform another five maximal isometric elbow flexion strength trials to assess retention of any potential strength gains. Elbow flexion torque and surface electromyography (SEMG) of the biceps and triceps were monitored concurrently. There was a significant ($P < 0.05$) increase in strength in both groups from block one (first five contractions) to block four (first retest) and from block one to block five (second retest). Both groups exhibited a similar linear increasing ($P < 0.05$) trend in biceps root-mean-square (RMS) SEMG amplitude. A significant ($P < 0.05$) decrease in triceps RMS SEMG amplitude was found between block one and block four for the distributed group. However, a significant ($P < 0.05$) increase was then found between block one and five for the massed group, and between blocks four and five for distributed group. These results suggest that there is flexibility in resistive exercise schedules. An increase in neural drive to the agonist muscle continued throughout testing. This was accompanied by a reduction in antagonist co activation that was a short-term (two weeks) training effect, dissipated over the longer rest interval (three months).

Keywords: ELECTROMYOGRAPHY, BICEPS BRACHII, ELBOW FLEXION, NEURAL ADAPTATION, RESISTANCE TRAINING, ANTAGONIST COACTIVATION

TABLE OF CONTENTS

Chapter		Page
	ABSTRACT.....	iii
1	INTRODUCTION.....	1
	Statement of the problem.....	2
	Significance of the study.....	2
	Basic Assumptions.....	2
	Definitions.....	3
	Delimitations.....	5
	Limitations.....	5
	Summary.....	6
2	REVIEW OF THE RELATED LITERATURE.....	7
	The “quick jumps” in strength phenomenon.....	7
	Massed versus distributed practice.....	8
	Postulated mechanisms.....	8
	Neural adaptations to resistance exercise.....	12
	Relationship between muscle size and strength.....	12
	Neuromotor coordination.....	13
	Agonist-antagonist coordination.....	13
	Recruitment of stabilizers and synergists.....	15
	Alterations in motor unit firing patterns.....	17
	Potential mechanisms.....	19

	Origin of the EMG interference pattern.....	21
	MFAPs.....	22
	MUAPs.....	23
	EMG-to-force relationship during isometric conditions.....	24
	Recording the electromyogram.....	27
	Surface electrodes versus indwelling electrodes.....	27
	Processing the EMG signal.....	28
	Criterion measures extracted from the EMG signal.....	29
	Root-mean-square amplitude.....	29
	Factors affecting electromyogram recording.....	30
	Motion artefact.....	32
3	MATERIALS AND METHODS.....	33
	Brief overview.....	33
	Sample size estimation and description of participants.....	33
	Experimental design.....	34
	Apparatus and testing position.....	35
	Measurement procedures.....	35
	Preliminary procedures.....	35
	Recording force and voluntary EMG.....	36
	Instructions to the participant.....	37
	Data reduction and criterion measures.	37
	Statistical analysis.....	38
4	RESULTS.....	40

	Subject characteristics.....	40
	Maximal elbow flexion force.....	40
	Electromyographic activity.....	41
	Biceps root-mean-square (bRMS) SEMG amplitude.....	41
	Triceps root-mean-square (tRMS) SEMG amplitude.....	42
5	DISCUSSION.....	43
	Strength measures.....	43
	Intraclass reliability of maximum isometric strength.....	45
	Electromyographic activity.....	46
	Intraclass reliability of bRMS SEMG amplitude.....	48
	Antagonist co-contraction.....	48
	Intraclass reliability of tRMS SEMG amplitude.....	50
6	SUMMARY AND CONCLUSIONS.....	51
	LIST OF FIGURES.....	53
	LIST OF TABLES.....	64
7	REFERENCES.....	69
8	APPENDIX A – Ethics approval.....	78
9	APPENDIX B – Informed consent document.....	81
10	APPENDIX C – Sample size estimation.....	86
11	APPENDIX D – Activity level questionnaire.....	88
12	APPENDIX E – Independent t-tests.....	92
13	APPENDIX F - ANOVA table for force.....	94
14	APPENDIX G - ANOVA table for biceps root-mean-square (brms)..	96

15	APPENDIX H - ANOVA table for triceps root-mean-square (trms)..	98
16	APPENDIX I - Mean force for five blocks of two different subjects..	100

INTRODUCTION

An interesting phenomenon surrounding the topic of resistance training is how quickly the neuromuscular system shows an increase in strength. Kroll ⁴⁴ was the first to introduce the “quick jump” theory when he showed that after three successive days of maximal isometric wrist flexion training, the subject’s strength actually increased 8-15% when re-tested three weeks later, and maintained this when re-tested three months later. The fact that these strength gains were still evident after long intervals between training sessions led Kroll to postulate that these quick jumps were caused by (1) the measurement schedule producing a motor learning effect, (2) the measurement schedule leading to a physiological strength development response, or (3) a combination of physiological training and learning. Later, Kroll ⁴⁷ suggested that the physiological changes were related to motor unit firing patterns and a neuromotor coordination mechanism involving antagonist-agonist activation patterns.

Since Kroll’s research in the 1960s, others have sought to answer the question of whether these quick jumps in strength were the result of physiological changes, neural changes, or motor learning. The fact that a quick jump in muscular strength is observed before muscle hypertrophy suggests some other mechanism unrelated to muscle physiology.⁵⁶ The finding that an increase in strength occurs with only a few contractions reinforces this view.^{43, 36}

Smith ⁷⁸ showed that graphs of the changes in strength associated with short-term, limited resistance exercise were remarkably similar to motor learning curves. This study explored the motor learning explanation for quick jumps in strength. If the quick jumps in strength phenomenon has a motor learning origin, then early increases in strength should

follow predictions based on established motor learning principles. The present study utilized the observed superiority of distributed versus massed practice as an experimental manipulation. We therefore hypothesized that participants who performed maximal isometric elbow flexion strength trials over consecutive days would exhibit a quick jump in strength, while those who completed the same number of trials on the same day would not.

Statement of the Problem. This study compared the effect of massed versus distributed practice in the acquisition of maximal isometric elbow flexion strength.

Significance of the study. If motor learning has a role in strength acquisition, then the principles of motor learning and skill acquisition should be considered when developing strength-training regimens. For example, if strength-training schedules can now be viewed as practice schedules that facilitate strength acquisition through skill learning, then the time interval between sessions and the selection of specific exercise will not be based on simply the injury and repair of muscle. An optimal balance must be sought between the two for a superior training response.

Basic Assumptions. The following assumptions were made in the present investigation:

1. Different practice schedules can produce different magnitudes of motor skill learning.
2. Once practice has taken place, its effects cannot be removed and its reliability cannot be assessed.
3. A change in maximum static strength can be expected due to practice.
4. The acquisition of muscular strength gains reflects motor skill learning.

5. Maximal elbow flexion force is the performance variable and changes in EMG are the by-products of learning to increase elbow flexion force.
6. Force is primarily attributable to the elbow flexors or a group of muscles (biceps brachii, brachialis and brachioradialis).
7. The two week and three month interval will ensure hypertrophy or other physiological adaptations endogenous to the muscle will have no influence upon the observed motor learning phenomenon.
8. Thus, learning can be inferred if strength gains are retained during time periods when no training has occurred.
9. Electromyographic activity is a measure of neural drive to the muscle.
10. It was assumed that the bioamplifier faithfully recorded the signal.

Definitions.

Co-contraction: the activation of multiple muscle groups around the joint. Often referred to as activation of agonist and antagonist muscle groups simultaneously.

Co-activation: is believed to occur in synergistic muscles to reduce the need for independent control of muscular activity during the movement in a multi-segmented limb, like the upper extremity.

Distributed practice: a practice regime in which periods of training are interspersed with rest periods.

Electromyography (EMG): the measurement of muscle action potentials through the use of indwelling or surface electrodes.

Isometric contraction: the muscle generates tension without an appreciable change in length.

Joint torque (moment of force): the dominant agonist muscle force causes rotation of the limb segment. The limb segment then applies a force that is parallel, in line with the load cell, but perpendicular to the axis of rotation.

Massed practice: a continuous block of practice with no rest period.

Measurement schedule: the way in which training is scheduled over time, i.e., intra- and inter-session intervals. If the measurement schedule is used to assess a motor skill, it may also constitute a practice schedule. Further, if the motor skill happens to be a resistance exercise task, it may also be a training schedule.

Motor unit: a single alpha-motor neuron and all the muscle fibers that it innervates.

Muscle coordination: the sequential pattern of inter-muscle activation that produces efficient movement.

Practice: successive repetitions of a motor behaviour.

Practice distribution: the way practice is scheduled, i.e., intra- and inter-session intervals.

Reliability: refers to the degree to which a measure is reproducible under baseline, or control conditions.

Delimitations.

1. This study included only right-hand dominant females, college-aged, from Brock University and the surrounding community.
2. Only isometric elbow flexion in the sagittal plane was studied.
3. Only one elbow flexor, the biceps brachii (BB) and one elbow extensor, the triceps lateral head (TLH) were assessed.
4. The 'long-term' retention test is delimited to 3 months.
5. Only one motor learning principle was used; the distribution of practice.

Limitations.

1. Since only right-handed individuals were tested in this study, the results may not apply to non-dominant limbs.
2. In the present study, elbow flexion in the sagittal plane was examined, thus results may not apply to other joints, when more than one joint is active, or during other types of muscle contraction.
3. Since only one of the elbow flexors was studied, the prediction of maximum torque only includes readings from this muscle and not other attributed muscles.
4. Because the retention tests were limited to three months, the observed adaptations may not apply to longer periods of time.

5. Since only one prediction of motor learning was investigated, strength acquisition by other motor learning phenomena was not assessed in the present study.
6. Rest periods in the massed group were necessary between trials to limit fatigue.

Summary. The quick jumps in strength that are associated with resistance training continue to lead researchers in a search for the underlying mechanisms of this phenomenon. Continued evidence that relates the initial increase in strength to neural factors stems from the increase in strength with few contractions before hypertrophy is evident, and the maintenance of strength even after long intervals between training sessions.

The question is, are these changes in strength a product of motor learning? If this is the case, then change in strength should follow motor learning predictions related to the distribution of practice.

Massed and distributed practice are important concepts in the acquisition of motor skills, and may be important in training of procedural skills (i.e., laparoscopic surgery). Practice distribution refers to the schedule of practice that a trainee is given.⁴⁹ It has been demonstrated repeatedly that distributed practice produces better performance scores, and possibly greater learning than massed practice.^{22,49}

Thus, the objective of this study was to determine the effects of massed versus distributed practice in the acquisition of maximal isometric elbow flexion strength and to provide insight and gain a better understanding of the role of motor learning in strength acquisition.

REVIEW OF THE RELATED LITERATURE

The “quick jumps” in strength phenomenon. Muscular strength has generally been related to the volume or size of the muscle tissue, so that a larger muscle would produce a greater force. However, there are many other mechanisms underlying strength besides muscle size. This became evident when a marked increase in strength was observed prior to any hypertrophy in the trained muscle, suggesting mechanisms other than changes in muscle physiology.⁴⁸

Kroll⁴³ administered five maximal isometric wrist flexion strength trials, on each of three consecutive test days. There was a significant (4%) increase across trials from the first to the last test session. To investigate this quick jump in strength phenomenon further, Kroll⁴⁴ repeated his original experiment but included two retest sessions, three weeks and three months later. An 8-15% increase was observed between the first test and retest condition, and it was retained over the three month period until the second retest. However, additional training that occurred as a result of the first retest condition failed to result in any further strength gains. These findings have been cross-validated for other muscles, such as the quadriceps,^{34, 70, 83} the plantar flexors,³⁶ the elbow extensors,²⁶ the abductor digiti minimi,⁶⁵ and the knee extensors.⁴¹

Kroll⁴⁴ postulated that these quick jumps were caused by (1) the measurement schedule producing motor learning effects, (2) the measurement schedule leading to a physiological strength development response, or (3) a combination of physiological training and learning.

Kroll ⁴⁵ later studied the effects of administering all contractions on a single test day. There were three groups corresponding to five, 10, and 15 maximal effort contractions of the wrist flexors. None of the three groups exhibited any increase in strength upon retest two weeks later, consistent with the physiological effects associated with detraining. The results taken together thus far indicated that 15 maximal effort contractions distributed over three consecutive days enhanced muscular strength, but, if all 15 contractions occurred on the same day, strength gains were absent. This is consistent with the motor learning principle that distributed practice is superior to massed practice. However, the observation has never been tested directly with resistance exercise, as studied here.

Massed versus distributed practice

Postulated Mechanism. The results of the majority of studies suggest that massed practice is detrimental to motor performance, with varied opinions of its effects on learning. ⁴⁹ Some researchers feel that there is less learning with massed practice, ⁷³ whereas others suggest that learning is not affected by massed practice, only performance. ^{57, 72, 75} As quoted in Lee and Genovese ⁴⁹, Magill stated the following:

The massed versus distributed practice schedule controversy should not be a controversy at all. The evidence seems rather convincing that the superiority of distributed practice over massed practice occurs as a performance attribute. When the amount of learning is taken into consideration, there does not appear to be any superiority of one over the other schedule (p. 374).

This inability to come up with a definite answer regarding learning and practice distribution is possibly the result of the variety of ways in which the assessment of learning has been conducted.⁴⁹ One general agreement is that learning needs to be separated from the temporary effects that take place in the acquisition period. This is accomplished by implementing a rest period following the practice session. The rest period is then followed by a retention test(s) to measure performance after the temporary effects from the acquisition schedule have dissipated. Generally the retention test(s) bring both groups together to a common distribution condition to allow the researcher to assess learning at the beginning of the retention test and to observe how long the difference lasts. This is referred to as a transfer design.

There are four measures to assess learning; absolute retention, relative retention, percent relative retention, and final score.⁴⁹ Each one of these measures utilizes some of the scores derived from the retention test(s) to determine if learning is occurring. The four measures to assess learning were defined in a review article by Lee and Genovese⁴⁹:

1. Absolute retention. The absolute retention score is the simplest measure of learning. This score is merely the performance on the retention test or the first trial (sometimes the first few trials) of the transfer test.
2. Relative retention. The relative retention measure considers the performance on the retention test (or the first few trial(s) of the transfer test) relative to the performance at the end of the acquisition trials. The measure is calculated by subtracting the final acquisition score from the retention score. This measure has also been termed the difference score or the reminiscence score.

3. Percent relative retention. Percent relative retention is an expression of the relative retention measure as a percent of the amount of original improvement during the acquisition trials. This measure is calculated using the relative retention score as the numerator and dividing by the amount of improvement from the beginning to the end of the acquisition practice trials.
4. Final score. The final score is calculated from designs that use a transfer test. This measure of learning is merely the last score(s) during the transfer test (pg. 278).

Of these four measures, Schmidt ⁷¹ has suggested that absolute retention is the only measure that provides accurate assessment of learning. His arguments were that performance effects do not contaminate absolute retention scores, and that they provide an initial measure of the potential learning without the convergence in performance associated with transfer tests. However, Christina and Shea ¹³ found that the absolute retention measure was just as likely to produce temporary performance factors, such as ceiling and floor effects. Ceiling effects are limitations, which are imposed by either the physiological-psychological sources or by the scoring system that places a maximum on the score that a subject can perform, whereas, floor effects are the converse of ceiling effects. ⁷³

Overall, the majority of studies have concluded that distributed practice creates a better environment to perform at a higher level, but does not necessarily provide superior learning. Learning refers to the acquisition of a skill that can be reproduced with great frequency, and is long lasting.⁴⁹ Administering retention tests no sooner than 20 minutes after practice accurately assesses learning, as Lintern ⁵² suggested that anything less than

20 minutes does not separate performance effects from learning. Long-term retention intervals have rarely been tested in distributed practice experiments. For the assessment of strength, research done by Hettinger³² showed that any strength gained in one day of training is completely lost within 14 days. For this reason, the effects of practice distribution on motor learning needs to be reassessed and examined over a longer period (i.e., two weeks to three months) to ensure that an individuals' performance level is not based on physiological factors.

A meta-analytic review by Donovan and Radosovich²² looked further into the complexity of practice distribution, as they broke down past research into the intertrial interval and task type in an attempt to identify if the superiority of distributed practice still applied. The specific task used in this thesis was an isometric contraction, therefore, based on Donovan and Radosovich's coding of task type, this was categorized into cluster one (C1), which embodied high physical requirements, but low overall complexity and mental requirements. The intertrial interval was then broken down into four categories, where the current study under investigation used spacing periods of one day between sessions for the distributed group, therefore placing it in Time Interval 4 (T4) for their meta-analysis. The results of their research were an overall effect size of 0.46 for the significant superiority of spaced practice over massed practice. Further analyses of task type revealed a clear superiority for spaced practiced over massed practice for T1 tasks (a simple motor task, i.e., isometric contraction). The effect size for T1 was 0.97, which was almost identical to that found in Lee and Genovese⁴⁹ meta-analysis of mostly psychomotor tasks ($d=0.96$). Further analysis for task type revealed that the mean difference between massed practice and spaced practice was reduced as the complexity of

the task increased (i.e., puzzle box task). An interesting finding in their meta-analysis was that, as the intertrial interval between the spaced practice conditions became shorter, thus moving closer to the massed practice conditions the result was higher mean differences. Therefore, it was suggested that a relatively short rest period is all that may be needed in a distributed practice schedule, as any more rest time between sessions may be detrimental—therefore an optimum rest-interval time should be sought.²²

Neural adaptations to resistance exercise

Relationship between muscle size and strength. It is widely accepted that a relationship exists between the amount of tension produced by a muscle and the cross-sectional area of that muscle. Anthropometric measures are the most common method for assessing strength, as body weight usually has a significant correlation with strength. However, the correlation between muscle fiber type composition and strength is only moderately significant, which leads many researchers to question the significance of the correlation.⁴⁸

Immobilization studies where the limb volume declines as does strength, creates further speculation surrounding the correlation between muscle size and strength. During the recovery period following immobilization there is an increase in strength with no change in limb volume. The rapid loss in strength and limb girth with limb immobilization, and the disproportionate increases evident in recovery have been associated with nervous system factors.⁴⁸

Darcus¹⁶ was the first to suggest that the nervous system needs to be considered when studying increases in muscle strength before looking at changes in muscle size.

When a seven-week intensive training program of the elbow flexors resulted in a 17% increase in strength, but produced no measurable difference in arm girth,²¹ it was evident that the nervous system plays a role, as it is responsible for the initiation and control of muscle contraction.

EMG allows us to distinguish whether changes in strength are occurring because of hypertrophic effects or muscle activation levels. When performing a maximal voluntary contraction, the muscle activation is a ratio between EMG and force.²¹ Moritani and de Vries⁶² showed that early force gains in the elbow flexors were represented by an increase in the integrated EMG (IEMG) to force ratio, which suggests the increase in strength is due to increased muscle activation. Using an eight-week progressive resistance-training program for the elbow flexors, Moritani and de Vries⁶³ further showed that as training proceeded, the ratio returned to pre-training values, representing muscle hypertrophy.

Neuromotor coordination

Agonist-antagonist coordination. When using the muscles of the upper limb, and taking direct measurements from the CNS, specific cells in the cerebellar cortex are selectively activated during co-contraction and reciprocal activation of agonist-antagonist muscles.^{19,79} The behaviour of the agonist-antagonist relationship has been studied mainly by observing EMG recordings from muscles during rapid movements producing the triphasic pattern. During limb acceleration there is the first observable activity of the agonist muscles, following that is the burst of antagonist activity and a reduction in

agonist activity as the limb slows down, ending with another burst from the agonist as the limb reaches the final position.¹⁹

When performing isometric contractions both the agonist and antagonist muscles are co-contracting to produce joint stiffness and there is unison behaviour of mean firing rates produced simultaneously called the common drive.¹⁸ This common drive indicates that the nervous system acts on the motoneuron pool in a uniform fashion and does not control the motor units individually. Observations made by De Luca and Mambrito,¹⁹ support the notion that the CNS controls the motoneuron pools of the agonist and antagonist muscles as if they were one pool when the muscles are doing the same task, such as an isometric contraction. Another suggestion is that there are three separate command channels that are centrally mediated comprised of two reciprocally organized flexion and extension channels and a shared co-activation channel.¹⁹

The nervous system stabilizes limb segments by coordinating the agonist and antagonist muscle activities. When an agonist muscle contracts, the antagonist muscle can contract at the same time to produce joint stiffness, such as when holding a heavy object, or can contract shortly after to slow down the movement of the limb, such as when reaching for an object. Therefore, when a high degree of precision is required to control the force, co-contraction of the antagonistic muscles is an integral part of the movement. The difference between the torques of the agonist and antagonist muscle is referred to as the net torque at a joint.¹⁹

The early stages of motor learning are characterized by antagonist co-contraction and extraneous muscle activity. Basmajian's³ theory of progressive inhibition suggests

that the CNS “learns” to minimize antagonist co-contraction to produce skilled, smooth movements. In support of this theory, Carolan and Cafarelli ¹¹ observed a decrease in biceps femoris EMG activity in association with an increase in maximal isometric knee extension strength following eight weeks of training. The lack of any observed increase in vastus lateralis EMG highlights the role of reduced antagonist co-contraction. From these results, it can be inferred that the amount of force that a muscle produces is greater when there is a lower activation of the antagonist muscle, thus less opposing force. From an energy standpoint, this increases the efficiency of agonist muscle contraction.

In theory progressive inhibition ³ has only limited support thus far. Gabriel has repeatedly shown that, whenever training results in an increase in strength or the speed of the limb movement, there is an increase in antagonist co-contraction.^{23, 25, 26} These results are consistent with the mechanical function of the antagonist outlined by Solomonow, et al. ⁷⁷ The antagonist muscle stabilizes the joint, and maintains its congruency in response to increases in agonist muscle force generation.

Recruitment of stabilizers and synergists. A synergist is a muscle that produces similar actions as another muscle, such as similar activation patterns in the generation of a movement or torque. This co-activation is believed to occur to reduce the need for independent control of muscular activity during the movement in a multi-segmented limb, like the upper extremity. It was hypothesized that the CNS creates synergies as a control strategy to simplify the control task and reduce the degrees of freedom.⁵ Whether the movement is related to posture during perturbation (stabilization) or is a goal-directed

movement of the hand, the co-activation of muscles represents muscle synergies or stereotyped patterns of muscle activation.⁹

Muscle synergies are usually studied by looking at the recorded EMG activity of agonist-antagonist muscles surrounding a joint. The measurements taken from the EMG include the time of peak EMG activity, the EMG onset times, or the broad time-course of EMG increase evoked by the initiation of voluntary movement or by a perturbation.⁹ Previous studies that looked at muscle activation during elbow-joint loads found synergies very uncommon in the elbow flexors in various directions,⁸ and noted no consistent patterns of co-activation in muscle pairs during a broad range of conditions.⁹

In a later study, Jamison and Caldwell,³⁵ studied synergism of the elbow flexors at various torque levels in the supination/pronation degree of freedom, and found that the synergistic relationships between muscles were dynamically relating to tasks in all applicable degrees of freedom. The synergistic muscles that EMG was recorded from included the brachioradialis, triceps brachii, biceps brachii, biceps brachii short head, and a medial and lateral site on biceps brachii long head. Their analysis showed that the CNS's pattern of stimulation to the muscles that results in flexion torque is dependent on the torque requirements in the supination/pronation degree of freedom, which shows that the muscular synergism for elbow flexion changes as a result of the second degree of freedom tasks. These factors all relate to the existence of task-specific motor unit subpopulations at the elbow. The recruitment or rate coding of these motor unit pools are evident in the changing EMG amplitudes in tasks with more than one degree of freedom.

Looking at the effects of training on muscle synergies, Tamaki et al.⁸⁰ had subjects perform low-level fatiguing contractions at the ankle joint. The functional interrelationships between synergistic muscle activities showed that relative activation of synergistic motor pools is not constant during a low-level fatiguing task, as alternating activity was observed among the synergists. Therefore, it remains unclear as to the motor control mechanisms responsible for the frequent changes in the combinations of motor units and motor pools during prolonged low-level force effort.

Alterations in motor unit firing patterns. The force of a muscle contraction can be graded by: (1) increasing the number of motor units (spatial recruitment); (2) increasing the frequency of motor units firing (temporal summation); and (3) changing from asynchronized to synchronized motor unit firing patterns. The following paragraphs will review training-related alterations in motor unit firing.

Proposed explanations for the increase in force produced from neuromuscular adaptations associated with training are related to an increased activation of the muscle as a result of changes in motor unit recruitment or firing patterns, as identified by numerous researchers.^{11, 28, 63, 69}

Specifically, Moriani and de Vries⁶³ found that the early changes in strength during an eight-week isokinetic training program of the elbow flexors were the result of significant changes in the muscle activation level, as a noted increase in integrated electromyography (IEMG) was found. The level of IEMG attained during maximal voluntary contraction (MVC) is a measure of the maximal activation of the muscle under voluntary conditions. The activation level is the result of the interaction of both facilitory

and inhibitory phenomena, which may act at various levels of the nervous system.⁶³ Hakkinen and Komi's²⁸ study also showed that maximum IEMG increased rapidly during early training of the leg muscles. Reasons for this were related to an increased recruitment of synchronously contracting motor units.

Synchronization of motor units was also evident in studies conducted by Milner-Brown, et al.^{60, 61} In these two studies, synchronous behaviours of motor units in the first dorsal interosseus muscle as a result of isometric contraction training were revealed by EMG methods as the mechanism for increased strength. More specifically, Milner-et al.⁶¹ studied weightlifters, as this population shows a higher amount of synchronization due to the regular use of their muscles exerting large, brief forces. It was suggested that physical training enhances neuronal pathways, so that supraspinal connections from the motor cortex to the spinal motoneurons send strong excitatory synaptic potentials to the motoneuron pool leading to a synchronous discharge of motoneurons.

In contrast Rutherford and Jones⁶⁹ suggested that after a 12-week training program, the improvement in the ability to lift weights was due to an increased ability to coordinate muscle synergies. The greater increase to lift training weights occurred with a much smaller increase in the isometric force produced by the quadriceps muscle. Therefore, it was suggested that improvement in the fixator muscles, such as the back and abdominal muscles, which stabilize the trunk, were the reason for the ability to lift heavier weights. The improvement in coordinating these fixator muscles seems to be a learning process, which results from establishing new neural pathways in the CNS. The preliminary data mentioned in, and conducted by Rutherford and Jones,⁶⁹ supports the

idea that coordination is an integral factor as detraining resulted in a loss of isometric strength, with a very small change in their ability to lift the training weights.

Kamen³⁶ studied maximal isometric strength training of the plantar flexors, and found early increases in strength on day one and two, but no significant strength changes on day six over the six consecutive test days. Subjects performed three maximal effort contractions lasting three seconds in duration with a one-minute rest period between trials. His findings were explained by the occurrence of doublets happening in the early contractions. Doublets occur when two bursts of motor units occur very quickly, increasing the tension development. Through repeated activation of motoneurons, it was hypothesized that the recurrent inhibitory Renshaw pathway was strengthened, resulting in a reduction of doublets, thus a reduction in the strength from doublets over time. However, van Cutsem et al.⁸¹ found dynamic training produced brief (2-5 ms) discharges of doublets, which were observed at the onset of a series of spikes but also after the EMG bursts. The percentage of firing doublets from motor units with different recruitment thresholds increased with training from 5.2-32.7%. Therefore, the extra doublets and increased maximal firing rate resulted from dynamic training and aided in the increase in the speed of voluntary muscle contraction.

Potential mechanisms. Heavy resistance training has been shown to increase neuromuscular drive. The increase in neural drive can be explained by peripheral, central, and psychological mechanisms. Aagaard, et al.,¹ evoked a H-reflex in the soleus muscle, and noted an elevated V-wave response, which shows an increase in spinal motoneuronal output. An H-reflex is an electrically evoked stretch reflex first described by Hoffmann

(1918), and can be used to assess the excitability of spinal α -motoneurons in Ia afferent synapses. The V-wave shows the overall magnitude of efferent motor output from the α -motoneuron pool because of activation from descending central pathways.¹ The results of this study suggest that heavy resistance training increases efferent neural drive, resulting in an increase in motoneuron firing frequency or possibly the recruitment of motoneurons that were not active in the past. This study did not identify if these adaptations from resistance training were occurring sub-cortically or were long-lasting effects at the cortical level.

To understand the central mechanisms, Carroll et al.¹² tested whether a simple movement against a large resistance would produce long-lasting changes in the corticospinal pathways. Using transcranial magnetic stimulation (TMS) and transcranial electrical stimulation (TES) it was shown that resistance training altered the input-output properties of corticospinal pathways. Specifically, the results of resistance training at specific magnitudes activated fewer motoneurons during muscle contraction due to a change in the organization of the CNS. Suggestions for the reduction in activated motor neurons were the following: altered intrinsic properties of the motoneurons, that the interneuronal circuitry was changed and had effects on the excitability of the motoneurons or the descending volleys, or the possibility of changes in the efficacy of synapses between motoneurons and corticospinal cells.¹² Therefore, within the spinal cord there is a change in the organization of the synaptic circuitry but no significant changes occurred in the motor cortex from resistance training.

Imagined contractions have been found to increase strength due to reorganization in the CNS, giving rise to psychological mechanisms that increase the neural drive. This was evident in a study done by Yue and Cole,⁸⁴ where subjects performed maximal voluntary isometric contractions of the abductor muscles of the fifth digit's metacarpophalangeal joint. Four weeks of training led to increased strength to the same degree as a group who imagined this training. This study suggests that the adaptations must be occurring in the CNS to mediate these strength gains. However, Herbert et al.,³⁰ tested this hypothesis by adding a third group (control group) and using the elbow flexors. Their findings are contradictory to Yue and Cole's,⁸⁴ as they found no significant differences between the training group and the imagined and control group. In fact, their results test the hypothesis of whether any adaptations of the CNS occur as a result of performing isometric elbow flexions. They found no increase in voluntary activation for any of the groups in their study.

Origin of the EMG interference pattern. One method of measuring muscular activity is the use of surface electromyography (SEMG). Recording electrodes are placed on the skin surface over the muscle to record its electrical activity. SEMG represents a global summation of muscle and motor unit activity during a voluntary or involuntary muscular contraction. The interference pattern is an AC signal, comprised of both negative and positive voltage directions. The pick-up area of the electrode records the algebraic summation of individual muscle action potentials for all the fibers of a single motor unit.¹⁹ Because motor units from different muscle fibers intermingle within the muscle belly, the electrode usually records from more than one motor unit.

Sherrington first introduced the term ‘motor unit’ in 1929 to describe a single alpha motor axon and all of the muscle fibers that it innervates (see Figure 1).⁵⁹ It is known as the functional unit of muscle contraction. One motor unit may include 10 muscle fibers for fine manipulative movements or up to 2-3000 muscle fibers if it is used for large gross movements. The strength of a reflex or a voluntary contraction depends on the number of activated motor units. Skeletal muscle consists of three different types of motor units that have a specific pattern of activation during voluntary contractions.¹⁰ As muscular force progressively increases so does the recruitment from the weakest slow twitch fibers to the stronger fatigue-resistant (FR-type) fibers and lastly the strongest fast-fatiguing (FF-type) fibers, according to Heinemann’s size principle.

Muscle fibers of several different motor units interdigitate throughout the muscle which results in as many as 20 to 50 muscle fibers that an electrode may pick up from more than one motor unit.⁴ Figure 2 illustrates two motor units, α_A and α_B . Muscle fibers one, four, and five are associated with α_A , and muscle fibers two and three are innervated by α_B . The muscle fiber action potentials (MFAP) from one, four and five summate to produce the motor unit action potential from α_A (MUAP_A). Likewise the MFAPs from fibers two and three summate to yield the MUAP_B. The two MUAPs summate linearly to form the basic building block of the interference pattern.

MFAPs. Muscle fiber action potentials (MFAPs) are the result of the CNS initiating the depolarization of a motoneuron that leads to depolarization of an associated muscle fiber creating an action potential. Skeletal muscle is made up of several muscle fibers that are grouped and controlled by motor neurons called a motor unit. A muscle contraction starts

when the CNS sends a signal via the somatic motor neuron to release acetylcholine (ACh). Acetylcholine binds to ACh receptor-channels on the motor end plate in the neuromuscular junction. The opening of these channels results in the influx of both Na^+ and K^+ across the sarcolemma. The electrochemical drive is greater for Na^+ , which results in a depolarization of the membrane, creating an end-plate potential (EPP) due to the addition of net positive charges. The action potential then travels across the fiber membrane and down the t-tubules, opening Ca^{2+} channels via voltage-sensitive dihydropyridine (DHP) receptors resulting in Ca^{2+} release in the sarcoplasmic reticulum. Once the calcium is released it binds with troponin, which reveals the binding sites on actin to allow a contraction.⁷⁶

MUAPs. Motor unit action potentials (MUAPs) are the main component of the power spectrum in the EMG signal. The SEMG is a representation of the spatial and temporal sum of individual MUAPs and is therefore longer in duration and larger in amplitude than a single fiber action potential. If motor units fire in an independent and random fashion, the total SEMG power will equal the sum of individual MUAP powers. The duration of MUAPs usually range from 2 to 10 msec with an amplitude ranging from $100\mu\text{V}$ to 2mV .⁵⁰

When performing a muscular contraction that requires maximal effort, motor units can fire in two short latency bursts prior to the start of a regular firing rate. The two bursts are called a doublet and can result in producing larger forces than expected from the addition of two motor unit force twitches. The time between the two firings is 2.9 to 20

ms and is most likely determined by enough depolarizing pressure still being imposed on the nerve cell during the recovery period of the first firing.⁵⁰

Rise time, duration, amplitude, number of phases and area of the recorded signal can describe the MUAP.⁵⁴ These factors are dependent on the location of the electrode, the size and type of electrode, the temporal dispersion of the single fiber action potentials at the recording site, the territory and fiber density, cross diameter of the muscle fibers and the properties of the surrounding tissue.⁵⁴ During muscular contractions, the conduction velocity and the depolarization zone of the muscle fibers are two factors that affect the shape of the MUAP.¹⁷

EMG-to-force relationships during isometric conditions. During constant-force isometric contractions, the propagation and depolarization of MFAPs are modified to produce time-dependent changes to the SEMG signal. Qualitatively speaking, there is a positive relationship between EMG and force in isometric contractions. As the tension increases within the muscle, so does the amplitude of EMG. Lippold⁵³ was the first to identify the linear relationship found between the integrated EMG and tension development in voluntary contractions. He studied isometric contractions of the gastrocnemius and soleus muscles during plantar flexion of the foot. Since his finding, many others have sought to determine a mathematical relationship between some measure of the EMG signal and the developed tension in human skeletal muscle in isometric tasks.⁶⁶ To identify whether this linear relationship between integrated EMG and isometric tension was also applicable to motor nerve stimulation, de Jong and Freund²⁰ applied a graded electrical stimulation to the ulnar nerve. EMG recorded from

the adductor pollicis brevis muscle showed a significant positive linear relationship between muscle action amplitude and tension at graded intensities. This finding revealed that not only voluntary contractions, but also evoked potentials and twitch tensions are equivalent indices of the relative numbers of muscle fibers activated.

The increase in EMG amplitude is related to increase in the motor unit firing rate and motor unit recruitment. When all the motor units have been recruited the additional increase in force during isometric conditions is accomplished by an increased rate of firing of the active units.⁵¹ There is a strong relationship between firing frequency and the power spectrum. This results in a shift of the power spectrum toward lower frequencies as the mean or median frequencies decrease but the amplitude may increase due to temporal overlap. There are numerous factors that need to be considered when recording EMG-force relationships during isometric contractions. These will be discussed in the following paragraphs.

The type of electrode configuration used when studying the EMG-to-force relationship is an important consideration as Moritani and de Vries⁶² found different EMG/force relationships when using monopolar versus bipolar electrodes. Due to the different relationships observed for the EMG-to-force relationship as being linear⁵³ or parabolic,⁶¹ Moritani and de Vries⁶² studied a variety of factors that may lead to these differences. When using monopolar surface electrodes, a linear relationship was observed between IEMG and force in the elbow flexors, and a non-linear relationship was found when using bipolar electrodes.

Hof and van den Berg³³ suggested possible reasons for these differences as being attributable to the joint position and groups of synergies. To further understand these discrepancies, Seigler et al.⁷⁴ studied two possible sources for the variability. They tested the variability through using different EMG signal processing techniques, and the variability as a result of repeated contractions in developing a relationship between muscle force and processed EMG for isometric contractions of the triceps surae muscle group. The different signal processing techniques included; second order Butterworth low pass filter; integration; moving average; and, integration with time reset. Each of the four processing techniques was used to develop the relationship between muscle force and processed EMG. Their results showed only slight variations between the different processing techniques, as the majority of the variability arose from repeated muscle contractions. This variability may arise due to the surface EMG signal providing only a localized view of the muscle activity. Therefore, due to the variations in experimental conditions from past studies, the discrepancy between linear and parabolic relationships in EMG/force may be largely attributable to the type and number of contractions used.

Methodological controls are important to ensure that the EMG-to-force relationship is consistent throughout an experiment. Electrode placement is critical. Any movement from the original position can affect the recorded amplitude of the MUAPs as a different set of active motor units could be recorded from. Lippold⁵³ observed that the relationship between EMG and tension varied considerably between experiments unless particular care was taken (i.e., taking photographs of electrode placements) to reproduce the location of the electrodes and limb posture in the experimental set-up. Another important consideration is the type of contraction, as movement will cause the skin

surface to shift, affecting the amplitude of the signal. Therefore, isometric contractions are best for ensuring stability of the recording because the only factors that would affect the MUAP are the depolarization zone of the muscle fibers and the conduction velocity.¹⁹

Recording the electromyogram

Surface electrodes versus indwelling electrodes. There are two types of electrodes for kinesiological EMG, surface electrodes and indwelling electrodes. Surface electrodes can be encased in a 'house', meaning that these active electrodes have built-in amplifiers, or they can be passive electrodes, which have no built in amplifier. Surface electrodes can be made of silver, stainless steel, gold or tin. The active electrodes are self-adhesive, reducing movement artefact and have an internal amplifier which increases the signal to noise ratio. Passive electrodes include grass electrodes, and require extensive skin preparation and a conducting gel, as there is no internal amplifier. Either a monopolar or a bipolar recording configuration can be used in recording EMG activity. Monopolar recording involves one recording electrode placed over the muscle belly, and one reference electrode placed over an electrically neutral site, like a bony prominence. Monopolar recordings allow for a 'crisp' representation of the EMG waveform, and are most often used for evoked potentials. Unfortunately they are susceptible to background noise in a non-isolated environment. Bipolar recording has two electrodes placed over the muscle belly and a ground electrode placed over an electrically neutral site.¹⁹ The signal that passes both electrodes is differentially amplified, while noise common to both the electrodes is, for the most part, rejected.

Advantages of surface electrodes include good reproducibility, ease of application and painlessness. The disadvantages are the possibility of cross talk when recording from smaller muscles, as they have a large pick-up area, and their limited use in recording activity from deep muscles. Surface electrodes have a bandwidth range from 20-600Hz.¹⁹

Intramuscular indwelling electrodes can detect a single motor unit action potential. A needle is placed into the muscle belly of the desired muscle and then retracted to leave the wire inside. The tips of the wires act as the recording site and may or may not be insulated. Advantages of indwelling electrodes are the following: the ability to test deep muscles, to test small muscles, to isolate specific areas within a large muscle, and they have a more specific pick-up area than surface electrodes. The disadvantages of indwelling electrodes include; the associated pain that comes from needle penetration, which may lead to spasticity or tightening of the muscles and the decrease in reproducibility of needle placement. The potential risk of infection is also a consideration when using needle electrodes. Indwelling electrodes have a bandwidth range from 2-1000Hz.¹⁹ Figure 3 represents a schematic of the two types of electrodes.

Processing the EMG signal. Prior to processing the signal, it is important to know the inherent frequency characteristics and sources of noise, thus the EMG signal frequency spectrum should be analyzed prior to filtering and choosing a sampling rate. It is generally recommended that the EMG signal be recorded with a low-frequency filter set around 10Hz, and a high-frequency filter set at 5-10kHz. Frequencies below 10Hz are associated with motion artefact, above 5kHz includes high frequency sources of noise. Selecting the minimum sampling frequency is crucial in order to correctly reproduce the

original analog information.¹⁹ The sampling rate should be at least twice the amount of the highest frequency recorded (Nyquist limit). This is generally 1000 samples/s or higher for surface EMG recordings. Therefore, to prevent the true signal from becoming distorted, a low-pass, anti-aliasing filter set at the Nyquist limit should be used. The anti-aliasing filter discards any frequencies that are not in the range of interest and should always be less than one half the sampling frequency in any A/D acquisition system.¹⁹

Criterion measures extracted from the EMG signal. The amplitude and the frequency are two important characteristics of the EMG signal. The amplitude is representative of the magnitude or amount of motor units firing, and can be determined by measuring the root mean square (RMS) derived from the peak-to-peak amplitudes of the MVC. The frequency of the EMG signal is the rate at which the motor units are firing. This can be broken down to the median frequency (MDF) or mean power frequency (MPF) of the EMG power spectrum as these are related to the average conduction velocity (CV) of the active fibers and the recruitment of new units.⁵¹ Factors that affect the MDF and MPF include; muscle fatigue, force level, muscle length, skin and muscle temperature, skin and muscle impedance, distribution of muscle fiber type, electrode properties and location as they all alter the shape of the power density spectrum.⁵¹

Root-mean-square amplitude. The present investigation will focus only on the time-domain analysis of the EMG signal. There are many different measures used to study the SEMG amplitude including integration, RMS and rectification. The RMS is indirectly related to the frequency content of the signal and is an indication of the half-power of the

signal (Parseval's theorem). In the case of SEMG, it would be an indication of generalized firing rate of the motor units.⁴²

The RMS amplitude for EMG can be calculated by the following equation:

$$RMS = \sqrt{\frac{1}{N} \sum_{i=1}^N EMG^2(t)},$$

where *EMG* is the amplitude of the signal in a given point in time (*t*), and *N* is the total number of EMG data points over time (*t*). The final value is then square-rooted to return the value to baseline measurements. RMS does not require full-wave rectification as it squares all the values of the interference pattern. The RMS amplitude of SEMG activity is used in physiological studies to monitor neural drive to the muscle. If SEMG amplitude increases it represents the recruitment of new motor units, increase of the firing rate of motor units or synchronizations of motor units.⁴²

Factors affected electromyogram recordings. Factors that affect the EMG recordings can be categorized into three groups: causative, intermediate, and deterministic, refer to Figure 4.¹⁹ The causative factors influence the intermediate factors and in turn influence the deterministic factors. The causative factors can be further divided into extrinsic and intrinsic factors.

The extrinsic factors are related to the electrode structure and the location of the electrode on the skin surface. De Luca¹⁹ suggested that many of these factors are important when considering electrode placement. The motor point of the muscle and the

myotendinous junction both influence the frequency and amplitude characteristics of the signal. Placing an electrode too close to the edge of a muscle can increase the chances of cross-talk, as the electrode may pick up activity from surrounding muscles.

The electrode detection surface area and shape affect the number of motor units and muscle fibers detected, which affect the average conduction velocity and the resulting frequency and amplitude content of the signal. Another consideration is inter-electrode distance as this alters the band-width of the differential electrode configuration.

The intrinsic causative factors cannot be controlled like the extrinsic factors as they are the anatomical, physiological and biochemical characteristics of the muscle.¹⁹ These include: the number of active motor units that are shown in the amplitude of the recorded EMG during a contraction; the different types of fibers in the muscle which change the interstitial fluid pH; the amount of blood flowing that removes metabolites; the fiber diameter which affects the amplitude and conduction velocity of the action potentials; the depth of the active fibers which determines the spatial filtering and influences the amplitude and frequency of the signal; the tissue located between the electrode and muscle surface which also affects the spatial filtering; and the ionic fluxes across the membrane and the depolarization zone.¹⁹

The intermediate factors include: the band-pass filtering, spatial filtering and detection volume characteristics of the electrode and the relative position of the electrode with respect to the active muscle; the superposition and conduction velocity of the action potentials, which affect the amplitude and frequency characteristics of the detected EMG signal; and cross-talk caused by recording nearby muscles.¹⁹ The varying filtering

capacities of the electrodes need to be taken into consideration as they can affect the signal the same way as adipose tissue does, by either only letting in high frequency signals, or only allowing in low frequency signals.⁴ The frequency-response characteristics and filtering specifications of the bioamplifier, in addition to the voltage range and precision (number of bits) of the analogue-to-digital converter, all affect the faithful representation of the recorded signal.

The deterministic factors have a direct impact on the recorded force and information in the EMG signal. These include: the firing frequency of motor units; different fiber type characteristics, de-recruitment and recruitment of motor units; synchronous discharge of motor units;² the number of detected-active motor units; the motor unit force-twitch; the shape, duration and amplitude of the motor unit action potentials; the muscle fibers mechanical interaction; and the motor units recruitment stability.¹⁹

Motion artefact. Motion artefact can result from loose electrodes at the skin surface, loose leads on the wires and the interface between the skin and the detection surface of the electrode. All these result in a change in the recorded activity representing noise. These artefacts have amplitudes of up to 500 mV and are of low frequency, ranging from 0 to 20 Hz.⁵⁴ Ways to decrease the noise resulting from motion artefact when using SEMG include proper cleaning of the skin surface, securing any loose wires, and ensuring all wires are properly secured in their connections.

MATERIALS AND METHODS

Brief Overview. All procedures used in this investigation have been reviewed and approved by the Brock University Human Ethics Board (File #: 03-271, see Appendix A). All participants were given an orientation in the laboratory and signed an informed consent document prior to testing (see Appendix B). Subjects were matched on the basis of predicted maximal elbow flexion strength and then were randomly assigned to the massed or distributed testing groups. Both groups performed 15 maximal isometric elbow flexion strength trials. The massed group completed all 15 trials in a single session, while the distributed group performed five trials on each of the three consecutive days.

Both groups completed a retention test consisting of five maximal isometric elbow flexion trials, two weeks following their first training session. A second retention test occurred three months later. Elbow flexion torque, biceps and triceps SEMG activity were monitored concurrently. As part of the experimental procedure the motor point of the biceps brachii was found before each test session so that placement of the bipolar electrode was not over the motor point.

Sample size estimation and description of participants. All subjects fit the following criteria: body mass index (BMI) of less than 30, right-hand dominant, healthy individuals who were not undertaking and had not recently undertaken high resistance upper-limb training. Females were chosen as subjects over males because males have less reliable isometric strength measures.⁴⁶

To estimate the power and sample size, Cohen's ¹⁴ case four formula was used for calculations using data from past research that looked at the same target population performing similar training.²⁷ From these data, the means, standard deviations, and reliability estimates for the criterion measure were obtained for isometric elbow flexion strength. A power of .80 and a level of significance of .05 were chosen in accordance with scientific convention.

After performing the calculations reported in Appendix C, the required sample needed to reasonably reject the null hypothesis when it was false was estimated at nine subjects. The "d" value obtained in the calculations was 3.79, which is actually higher than the maximum tabled "d" value. Since the design of this study required two groups who were matched based on their isometric elbow strength and randomly assigned into the massed or distributed group, a minimum of 20 subjects was required.

Experimental Design. Based on analyzing basic anthropometric measures in Gabriel et al.,²⁶ subjects were matched on the basis of predicted elbow flexion strength ($\hat{y}$), using the following equation:

$$\hat{y} = 44.081 + 1.050 \times \text{weight (N)} - 281.577 \times \text{circumference}$$

where, the circumference is that of the upper arm (circumference at the deltoid tubercle). The subjects were then ranked and assigned by matched pairs into either the massed or distributed group. The massed group performed 15 contractions in a single test session, while the distributed group completed five contractions on each of three consecutive days, for a total of 15 contractions. The retesting protocol took place two weeks

following the subject's first day of training, and again three-months following the first training day. For retests, the massed and distributed groups had the same testing protocol, which consisted of five maximal isometric elbow flexions. All contractions were five seconds in duration with a three-minute rest between each trial to minimize fatigue ⁶ (see Table 1). Subjects were instructed not to start any new training or new activities during the time frame of the study. Participants filled out an activity level questionnaire prior to their training and again on their second retest to monitor any new activities that may have been initiated (refer to Appendix D).

Apparatus and testing position. The experiment took place in the Faraday cage in the Raymond Nelson Reid Biomechanics laboratory at Brock University. A Faraday cage is a room surrounded by copper wire screening to reduce the effects of noise from surrounding electrical equipment. The subjects were seated in a straight backed chair with their right shoulder flexed to 90°, and the elbow flexed to 90° resting on an adjustable support. The right forearm was half-supinated and strapped in with a Velcro cuff below the styloid process to restrict movement and maintain the forearm at 90° relative to the upper arm. The load cell (JR3 Inc., Woodland, CA) was positioned perpendicular to the forearm in the sagittal plane. Subjects were also secured to the chair with Velcro straps to increase stability and minimize extraneous movements (see Figure5).

Measurement procedures

Preliminary procedures. The subject's first day in the lab was comprised of gathering anthropometric data. In addition to body weight, age and height, segmental limb lengths, girths and skin folds were measured for the right upper arm. These data were

incorporated into the strength prediction equation mentioned earlier and the subjects were ranked, matched and put into the appropriate practice distribution group. The subjects were then contacted as to their training and appointments were scheduled.

On the first testing day, subjects had their biceps, triceps, and clavicle on their right side lightly abraded with Nu-Prep and cleaned with alcohol to reduce signal impedance at the surface of the skin prior to electrode placement.

The electromyogram (EMG) was recorded from the biceps brachii using a bipolar surface electrode (DE-2.1, DelSys Inc., Boston, MA). The electrode was placed on the lower third of the biceps away from the motor point towards the distal tendon, as this placement shows the best reproducibility.³¹ Another electrode (DE-2.1, DelSys Inc., Boston, MA) was placed between the distal tendon and the top of the belly of the triceps lateral head to monitor activity in the antagonist muscle. A self-adhesive ground electrode was also secured over the clavicle. The bipolar surface electrodes amplified the signal with a fixed gain of 10. The EMG system (Bagnoli 4, Delsys Inc., Boston, MA) further amplified the signal (100x) before it was band-passed filtered (20-450 Hz).

Recording force and voluntary EMG. To measure the forces during testing, a load-cell was used (JR3 Inc., Woodland, CA). Prior to each experiment, the load-cell was calibrated using weights. Refer to Figure 5 for experimental set-up and electrode placement during isometric contractions. All signals were sent to a 32-bit A/D converter (BNC-2110, National Instruments), and sampled at 2048 Hz using a Computer-Based Oscilloscope and Data Acquisition System (DASyLab, DASYTEC National Instruments,

Amherst, NH). These recorded data were stored for further analysis on a Pentium III PC (Seanix Technology Inc., Blaine, WA).

Instructions to the participant. When the subjects were seated in the isometric testing apparatus, they were instructed to listen to a tape recording. This previously recorded tape instructed them to flex at the elbow as hard and as fast as possible when they heard “flex” in the recorded “ready and flex” statement. After five seconds the pre-recorded tape stated, “rest”, and the subjects were told to relax until told to “flex” again. Prior to each contraction subjects were verbally encouraged to give a maximal effort contraction.

To ensure that the locations of the electrode remained consistent throughout the experiment, indelible ink was used on the distributed group during their training. Participants were asked to try to maintain these markings themselves by using indelible ink over the fading tracings, or by coming into the lab to have the experimenter retrace the lines. Due to the long time period between testing sessions, a digital camera took a picture of the subject’s arm following their first training session. A tape measure was placed on the subject’s arm, starting at the tip of the third finger, and kept taut along the midline of the arm, as this acted as a reference to where the electrodes were placed. When subjects returned for their retest sessions, their picture was referred to.

Data reduction and Criterion measures. A two-second window in the middle of the five second isometric contraction was used to calculate the RMS amplitude of SEMG activity, for the biceps and triceps. The mean force value of that window was also obtained (see Figure 6). All data reduction was accomplished using MATLAB software (The Mathworks, Inc., Natick, MA).

Statistical Analysis. Absolute and relative retention measures are typically used for analysis in distribution practice studies to assess learning when there is a trial effect. However, preliminary analysis revealed no significant trial effect within each session, therefore we collapsed the five trials and took the average of the five trials to assess the performance across blocks. The average of the first five trials of the first test session were termed block one, the next five contractions block two and the last five contractions of the training termed block three. The first retest (two weeks later) and second retest (three months later) are referred to as block four and block five, respectively. All blocks were used for analysis. The criterion measures under consideration included the mean force, RMS SEMG amplitude of the biceps brachii (agonist activity) and RMS SEMG amplitude of the triceps long head (antagonist activity). A repeated measures ANOVA was used to test for significant differences. There was one between groups factor (massed versus distributed) and one within factor (blocks). All assumptions underlying the F-test were tested and respected. Post Hoc analysis was performed using Tukey's HSD to further evaluate any significant F-ratios, as this post hoc test is recommended for testing hypotheses for multiple pairwise comparisons.³⁹ A significance level of $P < 0.05$ was adopted for this study.

The effect of measurement upon securing reliable measures was assessed using a repeated measures analysis of variance (REANOVA). Reliability involves the consideration of two things. First, is how stable the group mean is across blocks. This was observed using a REANOVA. Second, is how consistent the individual scores are. The mean squares generated by REANOVA were used to calculate the Intraclass

correlation coefficient (*ICC*) to evaluate consistency. This study used the model (2, *k*)

ICC :⁶⁷

$$ICC(2, k) = \frac{BMS - EMS}{BMS + \frac{(RMS - EMS)}{n}}$$

Where *n* is the number of subjects, *BMS* is the between subjects mean squares, *RMS* is the residual mean square, and *EMS* is the error mean square obtained from the analysis of variance (ANOVA) table.⁶⁷

RESULTS

The following data presented in tables are organized so that block one is the mean of the first five (1-5) trials, block two is the mean of the second five trials (6-10), and block three is the mean of the third five trials (11-15). These three blocks comprise the training period for both the massed and distributed groups. Block four is the mean of the first retest (trials 16-20), occurring two weeks following their initial training day. Block five is the mean of the second retest (trials 21-25), which occurred three months following the initial training. The data presented in the graphs are organized so that only the baseline five contractions (block one) and the two-retests (blocks four and five) are shown, as they are the blocks of interest in detected learning.

Subject characteristics. Characteristics of the subjects in the two groups ($n=13$) are presented in Table 2. In both groups, no subjects began any new weight lifting activities during the time frame of the study as monitored by the activity level questionnaire. However, some subjects did participate in recreational activities during the study activities (i.e., biking, running), but an independent samples t -test revealed no significant difference ($P > 0.05$) on the measures. Preliminary analysis of baseline measures using an independent samples t -test found no significant differences between the two groups ($P > 0.05$) (see Appendix E), thus the two groups were matched well.

Maximal elbow flexion force. Between-group means were not significantly different ($P > 0.05$) for elbow flexion force in the two groups (see Appendix F). The means and standard deviations for the average maximal elbow flexion force are illustrated in Figure

7. The within-groups main effects for blocks were significant ($P < 0.05$), but there were no significant group-by-block interaction effects between the groups ($P > 0.05$). Thus, both the massed and distributed group followed the same pattern of change. Tukey's post hoc analysis for the massed group showed a significant ($P < 0.05$) increase in elbow flexion force between block one and retest blocks four and five (see Table 3). The total increase from block one to block four was 38.36N (24%), and from block one to block five it was 64.55N (49%). Post-hoc analysis for the distributed group also revealed a significant ($P < 0.05$) increase in elbow flexion torque between block one and the two-retest blocks (four and five). Inspection of Table 4 shows that the increase between block one and four was 19.42N (14%) while from block one to block five it was 43.85N (31%). The measure of the elbow flexion torque for subjects in the massed group across the five blocks was found to be reliable ($ICC = .90$). The same was true for the distributed group ($ICC = .85$).

Electromyographic Activity

Biceps root-mean-square (bRMS) amplitude. Between-group means were not significantly different ($P > 0.05$) for bRMS SEMG amplitude between the two groups (see Appendix G). The means and standard deviations for the average bRMS SEMG amplitude are depicted in Figure 8. The within-groups main effect for blocks was significant ($P < 0.05$), but there were no significant group-by-block interaction effects between the groups across blocks ($P > 0.05$). Thus, both the massed and distributed group followed the same pattern of change. Tukey's post hoc analysis for the massed group showed a significant ($P < 0.05$) increase in bRMS SEMG amplitude between block one and retest blocks four and five (see Table 3). The total increase from block one to block four was 97.03 μ V (27%), and from block one to block five was 117.69 μ V (33%).

However, post-hoc analysis for the distributed group showed that the 11.5% and 19.9% increase for the two retests sessions did not reach significance ($P=0.07$) (see Table 4). The bRMS SEMG for subjects in the massed group across the five blocks was found to be highly reliable ($ICC = .98$). The bRMS SEMG for subjects in the distributed group across the five blocks was also found to be highly reliable ($ICC = .92$).

Triceps root-mean-square (tRMS) amplitude. Between-group means were not significant ($P>0.05$) for tRMS SEMG amplitude between the two groups (see Appendix H). The means and standard deviations for the average tRMS SEMG amplitude are shown in Figure 9. The within-groups main effect for blocks was significant ($P<0.05$), but there were no significant group-by-block interaction effects between the groups across blocks ($P>0.05$). Therefore, both groups followed a similar pattern of change across blocks one, four and five. Tukey's post hoc analysis for the massed group showed a significant ($P<0.05$) increase in tRMS SEMG amplitude between block one and retest block five, and between the two retests (block four and block five) (see Table 3). The total increase from block one to block five was $53.69\mu V$ (110%), and the total increase from block four to block five was $68.12\mu V$ (139%). Further post-hoc analysis for the distributed group revealed a significant ($P<0.05$) decrease in tRMS SEMG amplitude between block one and retest block four. A significant ($P<0.05$) increase was then seen between the two-retest blocks (four and five). Inspection of Table 4 shows that the decrease between blocks one to four was $54.2\mu V$ (-64%), and the increase from block four to block five was $64.095\mu V$ (+75%). The tRMS SEMG amplitude for subjects in the massed group across the five blocks was found to be reliable ($ICC = .77$). This was also true for the distributed group ($ICC=.74$).

DISCUSSION

Since Kroll's research in the 1960s, many studies have explored the question of whether these quick jumps in strength are a result of physiological neural changes or motor learning. The fact that a quick jump in muscular strength is observed before muscle hypertrophy suggests that it is some other mechanism unrelated to muscle physiology.⁵⁶ This study explored the motor learning explanation for quick jumps in strength. If the quick jumps in strength phenomenon has a motor learning origin, then early increases in strength should follow predictions based on established motor learning theory. This study focused on the predicted superiority of distributed versus massed practice for motor skill learning⁴⁹ and the acquisition of muscular strength.

In this study the two separate groups (massed and distributed) were evaluated based on their maximal isometric elbow flexion strength scores and EMG amplitude after training. It was hypothesized that a greater increase in strength would be observed in the distributed group. In the following paragraphs, we will discuss the observed findings and the theoretical aspects of changes in strength and SEMG activity.

Strength measures. It was found that maximal isometric biceps brachii strength increased between the training session (block one) and the two retests (blocks four and five) in both the massed and distributed groups. Our baseline torque measurements for the two groups were 132.58N (13.5 Nm) and 143.74N (14.7 Nm), which are similar to Gabriel and Kroll's²⁷ baseline measurements of torque for their two groups (15.29 Nm and 15.72 Nm).

In resistance training studies it is common to find increases in strength of 30-40%.⁷ Our findings are consistent with these values as both the massed and distributed group showed significant improvements from block one to block four (24% and 14% respectively) and from block one to block five (49% and 31%, respectively). It was expected that only the distributed group would increase in strength in accordance with the established motor learning principle of the superiority of a distributed schedule. Therefore increases found in the massed group were surprising. In the case of resistance training of the biceps brachii muscle, it did not appear to matter if the practice schedule was implemented with rest periods. It seems that this muscle only needed to perform isometric contractions in one day to gain the strength benefits associated with motor learning.

There are several reasons as to the possibilities of why the results did not follow the predicted outcome. First, Kroll,⁴⁴ Hood and Forward,³⁴ Schneck and Forward,⁷⁰ Warshall,⁸³ and Kamen³⁶ have all shown that only a few contractions are required to significantly improve the strength of a muscle. The concept is that repeatedly practicing a specific movement creates enhanced motor programs to efficiently improve performance. Therefore, the CNS may have only required five repetitive contractions of the biceps brachii muscle to 'learn' the task.

Second, in the studies cited above, the task was a simple muscular contraction similar to the isometric elbow flexion used in this study. Therefore, with such a simple task, the spacing of practice is not the limiting factor, it is when the task becomes more complex that you may have to optimize the way you distribute practice. This was

suggested in Donovan and Radosevich²² meta-analytical review of distribution studies. They found the main differences between a massed and distributed schedule in regards to performance as being attributable to the task complexity—the more difficult the task (i.e. Flight stimulation exercises or puzzle boxes) the more favourable a distributed schedule. The spacing between trials when the task is highly complex allows the learner to process the cognitive aspects of the skill, and allows for mental practice.⁴⁹

A final suggestion for our results is that the time period between trials for the massed group (three minutes to eliminate fatigue) is different then past practice distribution studies where there was no rest at all between trials. In previous studies that utilized continuous practice like pursuit rotor, the main reason for better performance in the distributed group was that they were not fatigued. Thus learning may have not actually been affected in the massed group, only performance effects due to fatigue.⁵⁸

Past studies only used rest intervals of five minutes between the acquisition trials and retention tests, which did not allow sufficient time to separate out these performance effects. Therefore, the practice distribution theory may have only tested short-term performance, and not actual learning, as much longer retention tests (two weeks to three months later) may have revealed the consequence of the subjects training in regards to learning.

Intraclass Reliability of Maximum Isometric Strength. The reliability of a measure involves consideration of both the stability of group means and the consistency of individual scores. The block main effect was significant for both groups, indicating a lack of stability in the group means. However, the between subject mean squares were also

very high, resulting in a significant between subjects main effect. Thus, the lack of stability was compensated for by a high degree of consistency. That is, subjects were able to reproduce their own scores well enough, so that differences in scores between subjects could manifest themselves with little overlap (see Appendix I). Our *ICC* values for the massed and distributed group ($ICC = .90$, $ICC = .85$, respectively) are similar to those found in Gabriel and Kroll's²⁷ study ($ICC = .90$).

Electromyographic activity. To provide further insight into the mechanisms for changes in strength, we evaluated the recorded EMG activity of the biceps brachii and triceps lateral head. The RMS EMG amplitude was used for both the biceps brachii and triceps lateral head. The RMS amplitude of SEMG activity is used in physiological studies to monitor neural drive to the muscle. The findings in this study showed that the biceps RMS did significantly increase for the massed group from block one to the two retests (27% and 33%, respectively). A total increase in EMG activity of 117.7 μ V was seen in the massed group. Moritani and deVries⁶³ showed a 223 μ V increase in the muscle activation of the biceps. However their subjects followed an eight-week training program of the elbow flexors, where subjects trained three times a week.

Referring to Figure 8, you see the distributed groups bRMS SEMG followed the same linear trend as the massed group. However, no significant differences were seen between the blocks for the distributed group ($P = 0.07$). A possible suggestion for this non-significant finding is that the distributed group had a higher amount of skin fold thickness over the biceps, and the recorded EMG could be slightly impeded compared to the massed group. Even though the skin fold thicknesses were not significantly different

between the two groups ($P>0.05$), there was still an average of 2.33mm more adipose tissue over the biceps muscles for the distributed group. Even though the higher skin fold was non significant, it has real biological meaning. That is, the slight difference can have an impact on the tissue filtering effects upon the amplitude of the EMG signal.

Increases in the RMS SEMG amplitude are typically seen in strength training studies and are interpreted as an increase in neural drive.^{28, 29, 63} Explanations for the increase in force produced from neuromuscular adaptations associated with training are related to an increased activation of the muscle as a result of changes in motor unit recruitment or firing patterns as identified by numerous researchers^{11, 28, 63, 69, 81}

Patten et al.⁶⁵ found that the mean motor unit number increased in their training study from baseline values of 8.3 motor units, to 10.6 motor units 14 days later in the abductor digiti minimi. Their subjects trained five days a week for six weeks where subjects performed two sets of maximal isometric fifth finger abductions. In fact, they also found significant increases in motor unit discharge rate (MUDR) as early as 48 hours after initial training assessment of muscle strength, however the MUDR later returned to baseline values. The initial increase in MUDR and MVC force found in the early learning phase of their study was explained by the maximal MUDR being “highly amenable to rapid, task-specific alterations” (p. 548). Another explanation for increased MVC force is that altered motor unit recruitment thresholds found after isometric contractions result in a more excitable motor pool, which in turn leads to recruitment of more available motor units.⁶⁴ More specifically, Patten and Kamen⁶⁴ showed that training for force control in young subjects resulted in altered excitability of the agonist motor neuron pool.

Synchronization of motor units has also been found to be a factor in increased force production, especially in maximal effort contractions.³⁸ Synchronization of motor units was also evident in studies conducted by Milner-Brown, et al.^{60, 61} In the studies by Milner-Brown et al.,⁶⁰ and Milner-Brown et al.⁶¹ synchronous behaviours of motor units in the first dorsal interosseus muscle as a result of isometric contraction training were revealed as the mechanism for increased strength by surface-EMG methods. Therefore, Patten et al.'s⁶⁵ explanations for further increases in strength once the MUDR has returned to baseline may be due to improved motor unit recruitment (synchronization), changes in cortical mapping resulting from motor skill learning, and/or changes in agonist-antagonist muscle co-contraction (as found in the current study).

Intraclass Reliability of bRMS SEMG amplitude. The *ICC* values for bRMS SEMG amplitude were highly reliable in the massed and distributed group (.98 and .92, respectively). The EMG-RMS for the biceps brachii has been found to be highly reliable (*ICC* = .97) when elbow flexion force is examined over time.⁴⁰ The block main effect was only significant for the massed group, indicating a lack of stability in the group means. However, the between subject mean squares were also very high, resulting in a significant between subjects main effect. Thus, the lack of stability was compensated for by a high degree of consistency.

Antagonist co-contraction. To identify if changes in strength were the result of agonist-antagonist coordination, the tRMS was measured concurrently with the bRMS. Our findings found an initial drop in the tRMS from block one to block four, and then an increase from block one to block five was seen in both groups. The values obtained from

the tRMS SEMG amplitude ranged between 40-100 μV across the five blocks, which are within the same average tRMS found in Gabriel and Kroll's ²⁷ study (45 μV) with female subjects.

Our study failed to observe a long lasting decrease in antagonistic activity with the increase in strength, as found in Carolan and Cafarelli's ¹¹ study. In their study, hamstring co-activation during MVC extension decreased by 20% after one week of training. This co-activation appears to be a default strategy used by the nervous system when the specific muscle task is unclear, but once the task becomes familiar, the CNS changes the activation levels of the antagonist muscle so that the agonist muscle can increase the force output. Therefore, our findings from block one to block four in the distributed group do follow this theory of progressive inhibition, as a 64% decrease in tRMS activity was found. The decrease in co-contraction has to been shown to be a characteristic of motor learning.⁸² However from block four to block five, a significant increase in tRMS activity was observed in both groups. Thus, the decrease in antagonist co-contraction was short-term (i.e., two weeks) adaptation that was dissipated over the longer (three month) rest period, without further practice.

The question that arises is why the drop in block four for both groups and then an increase in block five. A suggestion may be that the retest two weeks following initial training resulted in a reduction of antagonistic activity based on Basmajian's theory of progressive inhibition.² The triceps muscle, through practice learned to become more silent so that the biceps could contract with greater force. That is, during the maximal effort contraction, the reduced co-contraction may result from learning the task.⁶⁴

However, the further increase in strength seen after three months required the triceps to become more active to compensate for the even greater torque development in the agonistic muscle. These results are consistent with the mechanical function of the antagonist outlined by Solomonow et al.⁷⁷ The integrity of the articular surfaces may be preserved by muscle coactivation patterns that result in a relatively even distribution of joint pressure.

Intraclass reliability of tRMS SEMG amplitude. The *ICC* values for tRMS in the massed (*ICC* = .76) and distributed group (*ICC* = .74) were moderately reliable, lower than what was found in Gabriel et al's²⁶ study for tRMS (*ICC* = .90). The block main effect was significant for both groups, indicating a lack of stability in the group means. However, the between subject mean squares were also very high, resulting in a significant between subjects main effect. Thus, the lack of stability was compensated for by a high degree of consistency. That is, subjects were able to reproduce their own scores well enough, so that differences in scores between subjects could manifest themselves with little overlap.

SUMMARY AND CONCLUSIONS

Differences in practice schedule had no effect on initial increases (quick jumps) in strength in this study. The similar linear trend across blocks for strength and bRMS SEMG amplitude activity for both groups suggests that resistance training all in one day or spread it out over three days resulted in early strength increases seen from learning. Learning was inferred by the continued increase without additional training.

The reduction in tRMS SEMG amplitude seen two weeks following initial training may reveal short-term practice effects, which aid in increased force production. Whereas the increase in tRMS SEMG amplitude three months following initial training may be an operative mechanism linked to the protection of the integrity of the musculoskeletal apparatus. All in all, the results did not support the massed versus distributed hypothesis for the quick jump in strength.

The results of this study suggest that when planning a resistance-training schedule a program can be created that will individually suit their weekly schedule. For example, if an individual has time for only one day of practice in learning a new simple resistance training skill, then the results of this study would suggest that they will gain the same benefits in just one-day of practice as they would if they came in three times that same week to practice. The idea that “more is better” with respect to intertrial time intervals with simple motor tasks was suggested by Donovan and Radosevich²² and future investigations could look into optimal intertrial times for developing strength in simple tasks. The fact that the quick jumps in strength phenomena was unaffected by the distribution of practice may have been due to the longer rest period in this group. Yet,

motor learning still did occur as assessed by the retention tests, therefore, additional investigations should continue to test intertrial intervals and other aspects of motor learning, such as the role of feedback. Finally, to subtract out learning effects only one session is needed, as multiple sessions may be unnecessary.

List of Figures

Figure 1. A motor unit is comprised of the motor neuron and all of the muscle fibers it innervates. Basmajian, J.V., and DeLuca, C.J. (1985). *Muscles Alive: Their function revealed by electromyography* (5th ed.). Baltimore, MD: Williams & Wilkins, Figure 1.7, page 12.

Figure 2. SEMG recordings from muscle fibers of two motor units. Kamen, G., & Caldwell, G.E. (1996). Physiology and interpretation of the electromyogram. *Journal of Clinical Neurophysiology*, 13(5), 366-384, Figure 1, page 368.

Figure 3. Surface electrodes vs. indwelling electrodes. Basmajian, J.V., and DeLuca, C.J. (1985). *Muscles Alive: Their function revealed by electromyography* (5th ed.). Baltimore, MD: Williams & Wilkins, Figure 2.17, page 54.

Figure 4. Factors that affect the EMG recordings. De Luca, C.J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13(2), 135-163.

Figure 5. Experimental set-up of EMG/force recordings on a load cell (JR3 Inc., Woodland, CA) in a Faraday cage at Brock University

Figure 6. A representative trial from one subject to show the recorded force from the elbow flexors (top panel), surface electromyographic (SEMG) activity of the biceps (middle panel) and the triceps (bottom panel) during a maximal isometric elbow flexion strength trial.

Figure 7. The means and standard errors (vertical bars) for maximal isometric elbow flexion force for the massed and distributed groups. These data represent the mean of the first five trials on session one (block one), the means of the five trials for the first retest session (block four) and the second retest session (block five).

Figure 8. The means and standard errors (vertical bars) for root-mean-square (RMS) surface electromyographic (SEMG) activity of the biceps brachii during maximal isometric elbow flexion force for the massed and distributed groups. These data represent the mean of the first five trials on session one (block one), the means of the five trials for the first retest session (block four) and the second retest session (block five).

Figure 9. The means and standard errors (vertical bars) for root-mean-square (RMS) surface electromyographic (SEMG) activity of the triceps brachii (lateral head) during maximal isometric elbow flexion force for the massed and distributed groups. These data represent the mean of the first five trials on session one (block one), the means of the five trials for the first retest session (block four) and the second retest session (block five).

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

List of Tables

Table 1. *Measurement schedule for training (days) and retesting schedules for the Massed (M) and distributed (D) groups*

Table 2. *Descriptive characteristics for the massed and distributed groups. Means and standard deviations for age, mass, height, body mass index (BMI), skin fold thickness over the biceps and strength.*

Table 3. *The means (M) and standard deviations (SD) for elbow flexion strength, biceps brachii root-mean-square surface electromyographic activity, triceps lateral head root-mean-square surface electromyographic activity, Intraclass correlation coefficients (ICC) for these measures for the massed group.*

Table 4. *The means (M) and standard deviations (SD) for elbow flexion strength, biceps brachii root-mean-square surface electromyographic activity, triceps lateral head root-mean-square surface electromyographic activity, Intraclass correlation coefficients (ICC) for these measures for the distributed group.*

Table 1

Days		2-weeks		3-months	
1	2	3	Re-test 1	Re-test 2	
M	15 MVC elbow flexions		5 MVC elbow flexions	5 MVC elbow flexions	
	3min rest		3min rest	3min rest	
D	5 MVC elbow flexions	5 MVC elbow flexions	5 MVC elbow flexions	5 MVC elbow flexions	
	3min rest	3min rest	3min rest	3min rest	

Table 2

Physical Characteristics	Massed	Distributed
	M $\pm$ SD	M $\pm$ SD
Age (yr)	24.08 $\pm$ 3.52	23.15 $\pm$ 3.74
Mass (kg)	59.47 $\pm$ 6.69	59.93 $\pm$ 8.01
Height (m)	1.65 $\pm$.05	1.66 $\pm$.06
BMI (kg $\cdot$ m ⁻²)	21.88 $\pm$ 1.59	21.87 $\pm$ 3.26
Skin fold thickness (biceps, mm)	8.55 $\pm$ 2.01	10.83 $\pm$ 5.87
Strength (N)	132.58 $\pm$ 37.67	143.74 $\pm$ 36.82
Sample size	13	13

Table 3

Block	Elbow flexion Strength	Biceps brachii RMS	Triceps lateral head RMS	
	(N)	(μV)	(μV)	
	Mean ± SD	Mean ± SD	Mean ± SD	
1	132.58 ± 37.66	355.07 ± 201.07	48.97 ± 34.57	
2	145.28 ± 43.71	400.46 ± 261.48	60.72 ± 43.37	
3	143.77 ± 46.55	397.62 ± 220.62	62.49 ± 45.11	
4	163.84 ± 44.78*	452.10 ± 279.12*	34.54 ± 46.85	
5	197.16 ± 36.18†‡	472.77 ± 257.49†	102.65 ± 42.25†‡	
(df)				
^{MS} Subjects (BMS)	12	81.157	280747.572	5607.085
^{MS} Blocks (RMS)	4	86.686	28652.869	8379.074
^{MS} Error (EMS)	48	2.595	5235.491	870.917
ICC		0.90	0.98	0.77

Note: ^{MS} stands for mean squares

* $P < 0.05$ for block 1 and block 4

† $P < 0.05$ for block 1 and block 5

‡ $P < 0.05$ for block 4 and block 5

Table 4

Day	Elbow flexion Strength	Biceps brachii RMS	Triceps lateral head RMS	
	(N)	(μV)	(μV)	
	Mean ± SD	Mean ± SD	Mean ± SD	
1	143.74± 36.82	291.94 ± 149.27	85.41 ± 59.74	
2	146.26 ± 21.82	298.70 ± 106.94	55.78 ± 45.56	
3	151.15 ± 22.25	325.45 ± 111.09	84.99 ± 57.72	
4	163.11 ± 27.78*	325.54 ± 126.46	31.21 ± 42.67*	
5	187.61 ± 25.44†‡	364.46 ± 148.81	95.31 ± 46.32‡	
(df)				
^{MS} Subjects (BMS)	12	369.248	65924.696	7229.298
^{MS} Blocks (RMS)	4	174.307	10630.766	9125.842
^{MS} Error (EMS)	48	97.755	4567.423	1428.538
ICC		0.85	0.92	0.74

Note: ^{MS} stands for mean squares

* $P < 0.05$ for block 1 and block 4

† $P < 0.05$ for block 1 and block 5

‡ $P < 0.05$ for block 4 and block 5

REFERENCES

1. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Halkjaer-Kristensen J, Dyhre-Poulsen P. Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. *J Appl Physiol* 2002; 92:2309-2318.
2. Arendt-Nielsen L, Mills K R. The relationship between mean power frequency of the EMG spectrum and muscle fiber conduction velocity. *Electroencephalogr Clin Neurophysiol* 1985; 60:130-134.
3. Basmajian JV. Motor learning and control: a working hypothesis. *Arch Phys Med Rehabil* 1977; 58:38-41.
4. Basmajian, JV, DeLuca CJ. *Muscles alive: Their function revealed by electromyography* (5th ed.). Baltimore, MD: Williams & Wilkins; 1985.
5. Bernstein NA. *The Co-ordination and regulation of movements*. London; Pergamon; 1967.
6. Bigland-Ritchie B, Johansson R, Lippold OCJ, Smith S, Woods JJ. Changes in motoneurone firing rates during sustained maximal voluntary contractions. *J Physiol (Lond)* 1983; 340:335-346.
7. Brooks G, Fahey T. *Fundamentals of Human Performance*: Macmillan Publishing Company, New York; 1987.
8. Buchanan TS, Almdale DPJ, Lewis JL, Rymer WZ. Characteristics of synergic relations during isometric contractions of human elbow muscles. *J Neurophysiol* 1986; 5:1225-1241.

9. Buchanan TS, Rovai GP, Rymer WZ. Strategies for muscle activation during isometric torque generation at the human elbow. *J Neurophysiol* 1989; 62:1201-1212.
10. Burke RE. Motor unit recruitment: What are the critical factors? *Clin Neurophysiol* 1981; 3:61-84.
11. Carolan B, Cafarelli, E. Adaptations after isometric resistance training. *J Appl Physiol* 1992; 73:911-917.
12. Carroll TJ, Riek S, Carson RG. The sites of neural adaptation induced by resistance training in humans. *J Physiol* 2002; 544:641-652.
13. Christina RW, Shea JB. The limitations of generalization based on restricted information. *Res Q* 1988; 59:291-297.
14. Cohen J. Statistical power analysis for the behavioral sciences. New York: Academic Press; 1969.
15. Daanen HAM, Mazure M, Holewijn M, Van der Velde EA. Reproducibility of the mean power frequency of the surface electromyogram. *Eur J Appl Physiol* 1990; 61:274-277.
16. Darcus HD. Discussion on an evaluation of the methods of increasing strength. *Proc R Soc Med* 1956; 49:999-1006.
17. De Luca CJ. The use of surface electromyography in biomechanics. *J Appl Biomech* 1997; 13:135-163.
18. De Luca CJ, LeFever RS, McCue MP, Xenakis AP. Controls scheme governing concurrently active human motor units during voluntary contractions. *J Physiol (Lond)* 1982; 329:113-128.

19. De Luca CJ, Mambrito B. Voluntary control of motor units in human antagonist muscles: Coactivation and reciprocal activation. *J Neurophysiol* 1987; 58:525-542.
20. de Jong RH, Freund FG. Relation between electromyogram and isometric twitch tension in human muscle. *Arch Phys Med Rehabil* 1967; October:539-542.
21. de Vries H. Efficiency of electrical activity as a measure of the functional state of muscle tissue. *Am J Phys Med* 1968; 47:10-22.
22. Donovan JJ, Radosevich DJ. A meta-analytic review of the distribution of practice effect: now you see it, now you don't. *J Appl Psychol* 1999; 84:795-805.
23. Gabriel DA. Changes in kinematic and EMG variability while practicing a maximal performance task. *J Electromyogr Kinesiol* 2002; 12:407-12.
24. Gabriel DA, Boucher JP. Effects of repetitive dynamic contractions upon electromechanical delay. *Eur J Appl Physiol Occup Physiol* 1998; 79:37-40.
25. Gabriel DA, Boucher JP. Practicing a maximal performance task: a cooperative strategy for muscle activity. *Res Q* 2000; 71: 217-228.
26. Gabriel DA, Basford J, An KA. Neural adaptations of fatigue: implications for muscle strength and training. *Med Sci Sports Exerc* 2001; 33:1354-1360.
27. Gabriel DA, Kroll WP. Isometric successive induction resistance exercise. *Clin Kinesiol* 1991; 45:30-37.
28. Hakkinen K, Komi PV. Electromyographic changes during strength training and detraining. *Med Sci Sports Exerc* 1983; 15: 455-60.

29. Hakkinen K, Allen M, Komi PV. Changes in isometric force and relaxation time, electromyographic and muscle fiber characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol Scand* 1985; 125:573-585.
30. Herbert RD, Dean C, Gandevia SC. Effects of real and imagined training on voluntary muscle activation during maximal isometric contractions. *Acta Physiol Scand* 1998; 163:361-368.
31. Hermens HJ, Boon K L, Zilvold G. The clinical use of surface EMG. *Electromyogr Clin Neurophysiol* 1984; 24:243-65.
32. Hettinger T. *Physiology of Strength*. Springfield, IL: Charles C. Thomas; 1961.
33. Hof AL, van der Berg J. Linearity between the weighted sum of the EMGs of the human triceps surae and the total torque. *J Biomech* 1977; 10: 529-39.
34. Hood LB, Forward EM. Strength variations in two determinations of maximal isometric conditions. *J Am Phys Ther Assoc* 1965; 45:1046-1053.
35. Jamison CJ, Caldwell GE. Muscle synergies and isometric torque production: Influence of supination and pronation level on elbow flexion. *J Neurophysiol* 1993; 70:947-960.
36. Kamen G. The acquisition of maximal isometric plantar flexor strength: a force-time curve analysis. *J Mot Behav* 1983; 15:63-73.
37. Kamen G, Caldwell GE. Physiology and interpretation of the electromyogram. *J Clin Neurophysiol* 1996; 13:366-384.
38. Kamen G, Roy A. Motor unit synchronization in young and elderly adults. *Eur J Appl Physiol* 2000; 81:403-410.

39. Kirk RE. Experimental design: Procedures for the Behavioral sciences. Belmont: CA: Brooks/Cole Publishing; 1968, p 99-244.
40. Kimura T, Hamada T, Wantanabe T, Maeda A, Oya T, Moritani T.
Mechanomyographic responses in human biceps brachii and soleus during sustained isometric contraction. Eur J Appl Physiol 2004; May 28.
41. Knight CA, Kamen G. Adaptations in muscular activation of the knee extensor muscles with strength training in young and older adults. J Electromyogr Kinesiol 2001; 11:405-412.
42. Kranz H, Cassell JF, Inbar GF. Relation between electromyogram and force in fatigue. J Appl Physiol 1985; 59:821-825.
43. Kroll WP. Reliability of a selected measure of human strength. Res Q 1962; 33:410-417.
44. Kroll WP. Reliability variations of strength in test-retest situations. Res Q 1963; 34:50-55.
45. Kroll WP. A reliable method of assessing isometric strength. Res Q 1963; 34:350-355.
46. Kroll WP. Test reliability and errors of measurement at several levels of absolute isometric strength. Res Q 1970; 41:155-163.
47. Kroll WP. Analysis of local muscular fatigue patterns. Res Q 1981; 52:523-539.
48. Kroll WP. Motor Learning/Control. Paper presentation, annual conference of National Association for Physical Education in Higher education, Indianapolis, Indiana, 1983; January 6-9.

49. Lee TD, Genovese ED. Distribution of practice in motor skill acquisition: learning and performance effects reconsidered. *Res Q* 1988; 59:277-287.
50. Lenman JAR, Ritchie AE. *Clinical Electromyography* (2nd Ed.) J.B. Philadelphia, USA: Lippincott Company; 1977.
51. Linnamo V, Strojnik V, Komi PV. Electromyogram power spectrum and features of the superimposed maximal M-wave during voluntary isometric actions in humans at different activation levels. *Eur J Appl Physiol* 2001; 86:28-33.
52. Lintern G. Distributed Practice: are there useful insights for application or theory. *Res Q* 1988; 59:298-302.
53. Lippold OCJ. The relationship between integrated action potential in a human muscle and its isometric tension. *J Physiol* 1952; 117:492-499.
54. Ludin HP. *Electromyography*. Amsterdam: New York : Elsevier; 1995.
55. Macaluso A, De Vito G, Felici F, Nimmo, MA. Electromyogram changes during sustained contraction after resistance training in women in their 3rd and 8th decades. *Eur J Appl Physiol* 2000; 82:418-424.
56. MacDougall JD, Gibala MF, Tarnopolsky MA, MacDonald JR, Internisano SA, Yarasheski KE. The time course for elevated muscle protein synthesis following heavy resistance training. *Can J Appl Physiol* 1995; 20:480-486.
57. Magill RA. *Motor Learning: Applications and concepts* (2nd ed.). Dubuque, IA: Brown; 1985.
58. Magill RA. The many faces of practice distribution in motor learning. *Res Q* 1988; 59:303-307.

59. McComas AJ. Motor units: how many, how large, what kind? *J Electromyogr Kinesiol* 1998; 8:391-402.
60. Milner-Brown HS, Stein RB, Yemm R. The contractile properties of human motor units during voluntary isometric contractions. *J Physiol* 1973; 228:285-306.
61. Milner-Brown HS, Stein RB, Lee RG. Synchronization of human motor units: possible roles of exercise and supraspinal reflexes. *Electroencephalogr Clin Neurophysiol* 1975; 38:245-254.
62. Moritani T, de Vries HA. Reexamination of the relationship between the surface IEMG and force of isometric contraction. *Am J Phys Med* 1978; 57:263-277.
63. Moritani T, de Vries HA. Neural factors versus hypertrophy in the time course of muscle strength gain. *Am J Phys Med* 1979; 58:115-130.
64. Patten C, Kamen G. Adaptations in motor unit discharge activity with force control training in young and older human adults. *Eur J Appl Physiol* 2000; 83:128-143.
65. Patten C, Kamen G, Rowland DM. Adaptations in maximal motor unit discharge rate to strength training in young and older adults. *Muscle Nerve* 2001; 24:542-550.
66. Perry J, Bekey GA. EMG-force relationships in skeletal muscle. *Crit Rev Biomed Eng* 1981; 1-22.
67. Portney LG, Watkins MP. *Foundations of clinical research: Applications to practice*. Norwalk, CN: Appleton & Lange; 1993.
68. Remple MS, Bruneau RM, Vandenberg PM, Goertzen C, Kleim JA. Sensitivity of cortical movement representations to motor experience: evidence that skill

- learning but not strength training induces cortical organization. *Behav Brain Res* 2001; 123:133-141.
69. Rutherford OM, Jones DA. The role of learning and coordination in strength training. *Eur J Appl Physiol* 1986; 55:100-105.
 70. Schenck JM, Forward EM. Quantitative strength changes with test repetitions. *J Am Phys Ther Assoc* 1965; 45:562-569.
 71. Schmidt RA. Retroactive interference and amount of original learning in verbal and motor tasks. *Res Q* 1971; 42:314-326.
 72. Schmidt RA. *Motor skills*. New York: Harper & Row; 1975.
 73. Schmidt RA. *Motor control and learning: A behavioural emphasis*. Champaign, IL: Human Kinetics; 1982.
 74. Siegler S, Hillstrom HJ, Freedman W, Moskowitz G. Effect of myoelectric signal processing on the relationship between muscle force and processed EMG. *Am J Phys Med* 1985; 64:130-149.
 75. Singer RN. *Motor Learning and human performance* (3rd ed.). New York: Macmillan; 1980.
 76. Silverthorn DU. *Human Physiology* (2nd Ed.). Prentice-Hall, Inc: N.J; 2001.
 77. Solomonow M, Guzzi A, Baratta R, Shoji H, D'Ambrosia R. EMG-force model of the elbows antagonistic muscle pair. *Am J Sports Med* 1986; 65:223-244.
 78. Smith LE. Strength increments following massed and distributed practice relative to motor learning. *Med Sci Sports Exerc* 1974; 6:154-157.
 79. Smith AM. The co-activation of antagonist muscles. *Can J Physiol Pharmacol* 1981; 59:733-747.

80. Tamaki H, Kitada K, Akamine T, Murata F, Sakou T, Kurata H. Alternate activity in the synergistic muscles during prolonged low-level contractions. *J Appl Physiol* 1998; 84:1943-1951.
81. van Cutsem M, Duchateau J, Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J Physiol* 1998; 15: 295-305.
82. Vorro J, Hobart D. Kinematic and myoelectric analysis analysis of skill acquisition. *Arch Phys Med Rehabil* 1981; 62:575-582.
83. Warshal D. The reliability of isometric strength gain in therapeutic assessment. *Am Correct Ther J* 1979; 33:188-191.
84. Yue G, Cole KJ. Strength increases from the motor program: comparison of training with maximum voluntary and imagined muscle contractions. *J Neurophysiol* 1992; 67:1114-1118.

APPENDIX A

Ethics Approval

Brock University

AS 302 **Senate Research Ethics Board**

Extensions 3943/3035, Room

DATE: **January 14, 2004**

FROM: Joe Engemann, Chair
Senate Research Ethics Board (REB)

TO: David A. Gabriel, Physical Education and Kinesiology
Kristina M. Calder

FILE: **03-271 Calder**

TITLE: **Massed and distributed practice in the acquisition of maximal isometric elbow flexion strength**

The Brock University Research Ethics Board has reviewed the above research proposal.

DECISION: **Accepted as is**

This project has been approved for the period of **January 14, 2004** to **July 30, 2004** subject to full REB ratification at the Research Ethics Board's next scheduled meeting. The approval may be extended upon request. ***The study may now proceed.***

Please note that the Research Ethics Board (REB) requires that you adhere to the protocol as last reviewed and approved by the REB. The Board must approve any modifications before they can be implemented. If you wish to modify your research project, please refer to www.BrockU.CA/researchservices/forms.html to complete the appropriate form ***REB-03 (2001) Request for Clearance of a Revision or Modification to an Ongoing Application.***

Adverse or unexpected events must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Principal Investigator, the safety of the participants and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and approvals of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-Council Policy Statement requires that ongoing research be monitored. A Final Report is required for all projects, with the exception of undergraduate projects, upon completion of the project. Researchers with projects lasting more than one year are required to submit a Continuing Review Report annually. The Office of Research Services will contact you when this form **REB-02 (2001) Continuing Review/Final Report** is required.

Please quote your REB file number on all future correspondence.

Deborah VanOosten, Research Ethics Officer
Brock University
Office of Research Services
500 Glenridge Avenue
St. Catharines, Ontario, Canada L2S 3A1
phone: (905)688-5550, ext. 3035 **fax:** (905)688-0748
email: deborah.vanoosten@brocku.ca
<http://www.brocku.ca/researchservices/humanethics.html>

APPENDIX B**Informed Consent Document**

BROCK UNIVERSITY DEPARTMENT OF APPLIED HEALTH SCIENCES**Informed Consent Form**

Title of Study: Training distribution and the acquisition of maximal isometric elbow flexion strength.

Principal Investigator: Kristina Calder
Biomechanics Master Student
Brock University
500 Glenridge Avenue
St. Catharines, ON
L2S 3A1
Phone: (905)-688-5550 ext. 4902
E-mail: calderkristina@hotmail.com

Supervising Professor: David A. Gabriel, Ph.D.
Associate Professor Biomechanics
Department of Physical Education
Brock University
Phone: (905) 688-5550 ext. 4362
E-mail: dgabriel@arnie.pec.brocku.ca

This study has been reviewed and approved by the Brock Research Ethics Board (File #03-271). The Brock Research Ethics Board requires written informed consent from participants prior to participation in a research study so that they are aware of the nature of the risks of participation and can decide to participate or not to participate in a free and informed manner. You are asked to read the following material to ensure that you are informed of the nature of this research study and how you will participate in it if you consent to do so. Signing this form will indicate that you have been so informed and that you give consent.

Introduction:

You are being asked to participate in research being conducted by Kristina Calder. This research is designed to examine the effects of training and the related neuromuscular activity in a muscle of the upper limb, following stimulation of an associated nerve. The ultimate goal of this study is to assess the effects of practice distributions in training in the acquisition of muscular strength, and to determine if these training effects are related to physiological changes or neural changes.

You will come to the Biomechanics Laboratory in the Welsh Complex at Brock University for a total of three test sessions if you are placed in group one (massed), or five sessions if you are placed in group two (distributed). After your training session, you will come back two weeks later for one testing session, and then 3 months later for one last testing session. Each session will last approximately one hour. All tests will be conducted by Kristina Calder. During each session you will be asked to sit in a chair with

an adjustable arm piece where you will place your right arm. You will perform elbow flexions as hard as you can for a maximum of three sets of five. Changes in muscle electrical activity will be monitored by placing electrodes over the elbow flexors and extensors. This is similar to the electrocardiogram wherein surface electrodes are placed on the chest to monitor electrical activity of the heart muscle.

Risks and Discomforts:

It is not possible to predict all possible risks or discomforts that a participant may experience in any research study. Based on previous studies with similar methodology, the present investigator anticipates no major risks or discomforts will occur in the present study.

Participants sometimes experience mild discomfort when the skin is gently cleaned and rubbed with a mild abrasive in preparation for electrode placement. On occasion, some subjects may experience skin irritation associated with the placement of the electrodes. This is usually very mild and goes away in a few hours, or a day.

Performing maximal contractions at the elbow, may cause some muscle soreness following.

Alternatives:

Needle electromyography is an alternative method for studying muscular activity. Surface electrodes therefore represent the least invasive means of recording the electrical activity of the muscle.

Volunteer Participation:

Participation in this study is voluntary. Refusal to participate will not result in any consequences to you. You will inform the investigator, Kristina Calder, of your intention to withdraw prior to removing yourself from this study.

Termination of Participation:

Participation in this research study may be terminated under the following circumstances. The investigator, Kristina Calder, may discontinue your involvement in the study at any time if it is felt to be in your best interest, if you not comply with study requirements, or if the study is stopped. You will be informed of any changes in the nature of the study of in the procedures described if they occur.

Potential Benefits:

You will receive no direct benefits from participating in this study. However, you should know that your willingness to serve as a subject for this experiment will help a Brock University researcher and other scientists develop new, non-invasive methods of assessing neuromuscular activity.

Costs and Compensation:

The cost of the test and procedures are free. You will not receive any form of compensation for your participation in this study.

Confidentiality:

Although data from this study may be published, confidentiality of information concerning all participants will be maintained. All the data will be coded without personal reference to you. Any personal information related to you will be kept in a locked office, to which only the Faculty Supervisor will have access. Names of participants or materials identifying participants will not be released without written permission except as such release is required by law.

Persons to Contact with Questions:

The investigator will be available to answer any questions concerning this research, now or in the future. You may contact the investigator, Kristina Calder, by telephone, at (905) 688-5550 ext. 4902, or by e-mail at calderkristina@hotmail.com. Alternatively, you may contact the supervising professor, David A. Gabriel, Ph.D., by telephone during office hours at (905) 688-5550 ext 4362, or by e-mail at dgabriel@arnie.pec.brocku.ca. Also, if questions arise about your rights as a research subject, you may contact the Director of the Office of Research Services at (905) 688-5550 ext. 4315. If you wish to speak with someone not involved in the study, please call Dr. Mike Plyley, Chair of Applied Health Sciences at (905) 688-5550 ext. 3383.

Consent to participate:

Certify that you have read all the above, asked questions and received answers concerning areas you did not understand, and have received satisfactory answers to these questions. You willingly give consent for participation in this study. (A copy of the consent form will be given to you).

Name of Participant (Please Print _____)

Signature of Participant

Date (day/month/year)

In addition to the considerations described in this document, the investigator fully intends to conduct all procedures with the subject's best interest uppermost in mind, to ensure the subject's safety and comfort.

I have fully explained the procedures of this study to the above volunteer. I believe that the person signing this form understands what is involved in this study and voluntarily agrees to participate.

Kristina Calder

Date (day/month/year)

If you wish to receive a summary of the results from this study, please complete the following information. A summary will be sent to you once all data have been analyzed. This summary will be maintained as part of your file that will be stored in a locked office. When and if the data are published, you may also have access to the results on the world wide web. Type the name of the Faculty Supervisor (David Gabriel) as part

of a search on MEDLINE at: HYPERLINK
<http://www.nlm.nih.gov/databases/freemedl.html>.

Name of Participant

Mailing Address:

Street, P.O. Box, Rural Route #, Apt. #

City

Province

Postal Code

APPENDIX C

Sample Size Estimation

Sample Size Estimation

Case Four Formula: Cohen (1969)

Where $d = \frac{d'_4}{(1-r)^{1/2}}$ and $d'_4 = \frac{Mx - My}{\sigma}$, the following calculations were made using

maximal voluntary isometric elbow flexion strength in pounds:

$$\text{Effect size: } Mx - My = 33.67 - 37.04 = 3.37$$

$$\text{Standard deviation (SD)} = 6.33$$

$$\text{Intraclass reliability coefficient (R)} = .98$$

$$d'_4 = 3.37 / 6.33 = 0.53$$

$$d = 0.53 / 0.14 = 3.79$$

$$\text{Confidence level} = 0.05$$

$$\text{Power} = 80$$

$$\text{Number of Subjects (N)} = 9$$

APPENDIX D

Activity Level Questionnaire

Activity Level Questionnaire

HISTORY OF PHYSICAL ACTIVITY

Instructions:

Here we want to know a little bit about your physical activity patterns over your lifetime. Specifically we are asking you about your occupational, household, exercise/sport activities. So break it down for us.

1. *Your occupational activities.* What jobs (paid or volunteer) have you done at least 8 hours a week for four months of the year over your lifetime? Please fill in the information in the appropriate boxes. Describe the job that you had, the age that you started working at this job and the age when you ended doing this job. Also list the number of years/months, the number of days per week, the number of hours per day and the intensity of the job.

No.	Description of Occupational Activity	Age Started	Age Ended	No. of Months/Year	No. of Days/Week	Time per day		Intensity of Activity *(1,2,3,4)
						Hours	Minutes	
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

****Intensity of occupational activities defined as:***

1 = jobs that require only sitting with minimal walking; **2** = jobs that require a minimal amount of physical effort such as standing and slow walking with no increase in heart rate or perspiration; **3** = jobs that require carrying lights loads (5-10lbs), continuous walking, mainly indoor activity and that would increase the heart rate slightly with light perspiration; **4** = jobs that require carrying heavy loads (>10lbs), brisk walking, climbing, outdoor activity, and an increase in heart rate, heavy sweating

2. *Your household activities.*

What kind of household/gardening activities have you done over your lifetime? Please only include those activities you have done at least 7 hours per week for four months of the year. Consider your typical day, then think about how many hour you spend doing household/gardening activities. Please fill in the information in the appropriate boxes.

No.	Description of Household activity (i.e., vacuuming, gardening, etc)	Age Started	Age Ended	Number of Months/Year	Number of Days/Week	Time per day		* Intensity of Activity 1, 2, 3, 4
						Hours	Minutes	
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

* **Intensity of household activity:** 1 = activities that can be done while sitting; 2 = activities that require minimal effort i.e. standing, slow walking, not much physical effort; 3= activities that are not exhausting, but increase heart rate slightly, light perspiration; 4 = activities that increase the heart rate and cause heavy sweating.

3. Your exercise/sport activities. What kind of exercise or sports have you done over your lifetime? Please report the activities you have done at least 2 hours per week for at least 4 months of the year. Besides sports and exercise we also want to know if you biked or walked to work/school. If you have done this please report it as exercise activity. Please begin by telling us what activities you did during your school years (physical education classes).

No.	Description of Exercise/ Sport Activities (i.e. walking, biking, running, weight lifting, etc)	Age Started	Age Ended	Frequency of Activity				Time per activity		*Intensity of Leisure Activity
				Days	Weeks	Months	Years	Hours	Minute	
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										

*** Intensity of activities defined as:** 1 = activities that are done while sitting; 2 = activities that require minimal effort (i.e., a light walk); 3 = activities that are not exhausting, that increase heart rate slightly, and may cause slight perspiration; 4 = activities that increase the heart rate and cause heavy sweating.

Appendix E

Independent t -tests for Physical Characteristics

Independent samples *t*-tests for physical characteristics of the subjects for the massed (M) and the distributed (D) groups

Physical characteristics		Mean	SD	<i>t</i>	<i>df</i>	Sig.
Height (cm)	M	164.65	5.31	-0.16	24	0.88
	D	165.76	6.09			
Weight (kg)	M	59.47	6.69	-0.16	24	0.87
	D	59.93	8.01			
BMI (kg·m ⁻²)	M	21.88	1.59	0.02	24	0.98
	D	21.87	3.25			
Strength (N)	M	13.52	3.84	-0.76	24	0.45
	D	14.65	3.75			
Biceps skin fold thickness (mm)	M	8.55	2.01	0.02	24	0.99
	D	10.83	5.87			

Appendix F

Repeated measures ANOVA table for force

Repeated measures analysis of variance (ANOVA) table for force.

Source of Variation	<i>df</i>	SS	MS	F-ratio	<i>P</i>
Between Subjects					
Group	1	1.154	1.154	0.021	0.887
Error	24	1343.137	55.964		
Within Subjects					
Between blocks	4	503.868	125.967	54.399	0.001
Blocks X Group	4	17.181	4.295	1.855	0.125
Error	96	222.300	2.316		

Appendix G

Repeated measures ANOVA table for bRMS

Repeated measures analysis of variance (ANOVA) table for biceps root-mean-square (brms).

Source of Variation	<i>df</i>	SS	MS	F-ratio	<i>P</i>
Between Subjects					
Group	1	289535.360	289535.360	1.67	0.209
Error	24	4160067.215	173336.134		
Within Subjects					
Between blocks	4	139237.564	34809.391	7.102	0.001
Blocks X Group	4	17896.974	4474.243	0.913	0.460
Error	96	470539.890	4901.457		

Appendix H

Repeated measures ANOVA table for tRMS

Repeated measures analysis of variance (ANOVA) table for triceps root-mean-square (trms).

Source of Variation	<i>df</i>	SS	MS	F-ratio	<i>P</i>
Between Subjects					
Group	1	2441.228	2441.228	0.380	0.543
Error	24	154036.594	6418.191		
Within Subjects					
Between blocks	4	14157.846	3539.461	3.079	0.039
Blocks X Group	4	10065.001	2516.250	2.189	0.105
Error	96	110373.793	1149.727		

APPENDIX I

Representation of the mean of five strength trials across the five blocks for two separate subjects

Figure. Mean force of five blocks of maximal effort isometric contractions for two different subjects.