Strength, CSA and specific tension changes in trained individuals in response to resistance training programs that are different in eccentric load

by

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We accept this thesis as conforming to the required standard

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ABSTRACT

The purpose of this study was to compare strength changes elicited by two different strength training programs of equal concentric loads but that differ in eccentric loads, on trained individuals. College males (21-29 years) were randomly assigned to either the conventional training group (CV)(n = 10, weight 81.6+/-5.9 kg, height 178.0+/-6.2 cm) or the supramaximal eccentric training group (SME) (n = 8, weight 80.4+/-2.8 kg, height 179.9+/-5.8 cm). Training of the forearm flexors and extensors was performed 2 to 3 times per week for 9 weeks. The CV group performed 4 sets of 10 repetitions to failure at a load equaling 75% of concentric 1RM. The SME group performed 3 sets of 10 repetitions to failure at a concentric load of 75% and an eccentric load of 110-120%. Concentric 1RM and eccentric muscle performance (number of reps performed at 130% concentric 1RM) were measured at weeks 0, 3, 6, and 9 while specific tension and muscle CSA were measured at weeks 0 and 9. Significant ($p<0.05$) increases in forearm flexor and extensor concentric 1RM and specific tension were observed in both training groups. Significantly greater gains in concentric 1RM of the forearm extensors were found in the SME group in comparison to the CV group. Significant decrements in eccentric muscle performance was observed in the forearm flexors and extensors of both training groups. However, the pattern of decrease was different between the two groups. No differences in muscle CSA occurred in either group. These findings suggest that in trained individuals, CV and SME training protocols are effective at increasing concentric strength as a result of neural adaptations (increases in specific tension). Further, the advantage of SME training could be related to muscle composition and architecture.

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Dedication

To my parents, Carol and Larry, and my sister Andrea. For your endless love and support and for instilling the values of commitment, perseverance and devotion, I thank-you.

"The reward of a thing well done, is to have it done"

-Ralph Waldo Emerson

x

Special Contributors

Front Runners

Sub-cycle

Island Runner

Fairfield cycle

Oakbay cycle

Rider’s cycle

INTRODUCTION

In sport, the force a muscle can exert constitutes an important element of physical performance. Strength is defined as the peak force, torque or tension a muscle can generate during a maximal voluntary contraction (Kraemer, 1992). Maximum strength is dependent upon the level of functioning of the neuromuscular system (Sale, 1988; Sale, 1992). Alterations to the functional level of the neuromuscular system, in response to resistance training, produce increases in maximal strength. Adaptations by the neuromuscular system exist as neural, muscular or a combination of both (Sale). The type of adaptation elicited is contingent upon training status of the athlete as well as the intensity of resistance training (Moritani & Devries, 1979; Hakkinen, 1985; Moritani, 1992).

Gains in strength without concomitant hypertrophy is considered to be evidence of an increase in the ability of the nervous system to activate contracting muscles (Sale, 1988; Poliquin, 1990). Neural mechanisms responsible for enhancing strength include a) recruitment of a greater number of available muscle fibers, b) elevated firing frequency of activated motor units, c) more effective synchronization of contracting motor units, and d) a reduction of inhibitory or protective mechanisms (Sale). These adaptations are characterized through measurable increases in integrated electromyography (iEMG) and increases in specific tension (force produced per unit of muscle cross-sectional area).

Strength is also contingent on muscle cross-sectional area (CSA). Because a larger muscle contains the potential to develop greater forces, muscle hypertrophy invoked through strength training is critical to increasing maximal strength (Sale, 1992). Increases in the amount of contractile protein content within muscle fibers produces the hypertrophic response that contributes to an increase in maximal strength.

Initial strength gains, elicited through resistance training, are pronounced and rapid and are primarily accounted for by neural factors (Mortitani & Devries, 1979; Moritani, 1992). As training progresses, the contribution of hypertrophic factors gradually emerge (Moritani & Devries; Komi, 1986, Moritani). With the performance of prolonged strength training, further muscular adaptations are limited thus compromising strength gains (Hakkinen, Alen & Komi, 1985; Hakkinen, Alen, Komi & Kauhanan, 1987; Moritani). At this point in training it is generally accepted that the volume and intensity of training must be substantial to produce further increases in strength (Hakkinen, Alen, Komi, & Kauhanan). With trained subjects, Wilson (1995), observed strength increases only in those subjects who trained with heavy loads (80-90% of concentric maximum). Further, following high intensity training, neural adaptations have been observed in resistance trained subjects. During the last 12 weeks of a 24-week resistance training study, training loads of 80-120% of concentric maximum were necessary to increase neural drive as reflected by iEMG levels. Corresponding to the increases in iEMG were increases in muscle strength (Hakkinen, Alen & Komi). Elite power lifters, who trained at high loading intensities (1-3 RM), elicited similar responses (Hakkinen, Alen, Komi & Kauhanan).

The above studies appear to support the belief that the magnitude of the resistance training load is fundamentally important for increasing strength as a result of resistance training (Dudley, Tesch, Miller & Buchanan, 1991). Atha (1981) suggests that the load applied to the musculature is the most important stimulus for enhancing strength. The potential to achieve the greatest possible loads occurs during eccentric muscle actions (Komi & Buskirk, 1972; Johnson, Adamczyk, Tennoe & Stromme, 1976).

An eccentric action is defined as the production of force while the muscle is lengthening (Kraemer, 1992). It has been postulated that the potential to generate muscle tension is 32% greater during an eccentric action when compared to a concentric contraction. (Atha, 1981). During muscle lengthening, preferential recruitment exists for type II muscle fibers (Nardone, Romano, & Schieppetti, 1989). Type II muscle fibers are larger and discharge at a greater rate than type I fibers, and are therefore capable of generating more force (Sale, 1987). Furthermore, assistance provided by the elastic recoil properties of muscle contribute to the muscle tension created during resisted muscle lengthening (Zernicke & Loitz, 1992).

It has been observed that eccentric contractions are essential for inducing maximal increases in muscle size and strength (Coté, Simoneau & Legassé, 1988; Dudley, Tesch, Miller & Buchanan, 1991; Tesch & Colliander, 1991; Hather, Tesch, Buchanan & Dudley, 1991; O'Hagan, Sale, MacDougall & Garner, 1994). When performed independently at a load greater than concentric maximum (1RM), eccentric contractions proved comparable (Rutherford & Jones, 1987, Johnson, Adamzyk, Tonnoe & Stromme,

1976) and more beneficial (Komi & Buskirk, 1972) than concentric-only training for improving strength. In a recent study, eccentric training at a load greater than concentric 1RM produced strength improvements similar to that of concentric combined with eccentric training (Ben-Sira, Ayalon & Tavi, 1996). Results from the above studies are difficult to interpret because of a) use of untrained subjects, b) unequal training volume between training groups, c) training loads were not optimal and d) mode of training was different from testing. Using trained subjects, Hakkinen & Komi (1981) combined eccentric training at a load greater than concentric 1RM with concentric training and concluded that a combination of concentric and eccentric training is more effective than the independent use of either contraction.

The physiological characteristics of eccentric actions may explain the need for eccentric actions as part of a training program. Preferential recruitment of type II muscle fibers occurs during resisted muscle lengthening (Nardone, Romano, & Schieppetti, 1989). It is the fast twitch muscle fibers that a greater responsiveness to hypertrophic adaptation (Hakkinen, Alen & Komi, 1985; Komi, 1986; MacDougall, 1992). Further, greater muscle "damage" of the type II muscle fibers is associated with eccentric contractions (Cote, Simoneau, Legasse, et al., 1988). Muscle damage may stimulate protein synthesis, as a result of a repair process, leading to hypertrophy (MacDougall, 1985). Exposure to high loads, that are possible through eccentric training, may desensitize the golgi tendon organ (Wilson, 1995). The golgi tendon organ relays inhibitory feedback in response to high levels of tension within the muscle. Resistance training with a significant eccentric component may be beneficial in disinhibiting this reflex. Responsiveness to training seems to be a function of connective tissue that is utilized during eccentric contractions (Zernicke & Loitz, 1992). Adaptations assumed by connective tissue may alter the transmission of forces generated by contracting muscles resulting in a change in the biomechanics of the muscle bone- lever system. As a result of these properties and the high resistances permitted under eccentric conditions, incorporation of these actions at high loads, should produce an intense training stimulus even for trained subjects.

Previous evidence has proposed that training loads necessary to enhance strength development in well trained individuals must be of a sufficient magnitude (80-120%) (Hakkinen & Komi, 1981; Hakkinen, Alen & Komi, 1985; Hakkinen, Alen, Komi & Kauhanan, 1987). As concentric force production is less than eccentric force, the magnitude of the training load is limited to the concentric strength of a muscle. As a result, the load during the eccentric contractions may be ineffective in contributing to the strength stimulus. If magnitude of the training load is a critical component of the strength stimulus, a training program, which changes in load to accommodate the force capabilities of each contraction type, could prove to be a more effective training stimulus. Therefore the purpose of this study was to compare and identify the strength changes produced by two different strength training programs, that possess equal concentric loads but differ in eccentric loads, on trained individuals and to examine if the strength changes produced are a result of neural or muscular contributions.

STATEMENT OF THE PROBLEM

Three problems have been identified:

1. To identify the effects of a standard resistance training program (4 sets of 10 repetitions @ approximately 75% concentric 1RM) on the strength of the forearm flexors and extensors in trained subjects.

2. To identify the effects of a predominantly eccentric resistance training program (3 sets of 10 repetitions @ approximately 75% concentric 1RM during concentric contractions and @ approximately 110- 120% concentric 1RM during eccentric contractions) on the strength of the forearm flexors and extensors in trained subjects.

3. To identify if significant differences exist in strength development between the two resistance training programs. In addition this study will examine whether or not the differences in strength produced by the two training programs are due to neural (specific tension) or muscular (muscle CSA) adaptations.

HYPOTHESES

The following hypotheses were tested:

Ha 1: The supramaximal eccentric training program would produce significantly greater increases in muscle CSA of trained subjects compared to a standard resistance training program.

Ha 2: The supramaximal eccentric training program would produce significantly greater increases in specific tension of trained subjects compared to a standard resistance training program.

Ha 3: The supramaximal eccentric training program would produce significantly greater increases in the following strength measures of trained subjects compared to a standard resistance training program.

Ha 3a: Concentric 1RM forearm extensor strength.

Ha 3b: Concentric 1RM forearm flexor strength.

Ha 3c: Eccentric forearm extensor strength.

Ha 3d: Eccentric forearm flexor strength.

ASSUMPTIONS

1. Tension is a necessary stimulus for strength enhancement
2. The training programs would result in measurable increases in strength and muscle CSA.
3. The study was of sufficient duration to allow for differences in the training programs to emerge.
4. Subjects were responsive to training.
5. Specific tension is a measure of neural adaptation.

DELIMITATIONS

1. Trained subjects were used. Trained subjects may be limited to the type and amount of response elicited through resistance training.
2. Only pre-training and post-training muscle CSA measurements were taken. Consequently, the only comparisons that could be made involved the pre- and post-training measures.
3. Resistance training was performed for only nine weeks.
4. Differences in training volume may have developed, as repetitions completed may not always correspond to the pre-set intensity.

LIMITATIONS

1. Subjects followed the training procedures.
2. Muscle fiber-type composition of the subjects may have been different. This could have affected the magnitude of response to resistance training.

3. Training status of the subjects may have been different and resulted in different types of adaptations to the training.

DEFINITIONS

Concentric 1RM:

The maximum amount of weight which can be lifted during 1 concentric repetition.

Concentric Contraction:

A contraction in which the muscle is producing force as it is shortening (Kraemer, 1992).

Eccentric action:

A contraction in which the muscle is producing force while lengthening (Kraemer, 1992).

Eccentric Strength:

The number of eccentric repetitions that can be performed at a load of 130 concentric 1RM while rate of lengthening is controlled.

Failure:

When fatigue will not permit another repetition to be completed adhering to the protocol described in the methodology.

Forearm Extensors:

Triceps brachii.

Forearm Flexors:

Biceps brachii, biceps brachialis and brachioradialis.

Repetition:

A concentric contraction coupled to an eccentric contraction.

Resistance Training:

Muscles working against a force in a repetitive fashion to the extent to which the muscle adapts and becomes stronger (Tesch, 1992).

Specific Tension:

The force generated per unit of muscle area (kg·cm$^{2^{-1}}$) [Garfinkel & Cafarelli, 1992].

Strength:

In the present study strength was defined as the maximum weight that can be lifted concentrically (concentric strength).

Supramaximal Load:

A training load that is greater than concentric 1RM.

Training Volume:

Volume was calculated by the following formula: repetitions x sets x load (O'Hagan, Sale, MacDougall & Garner, 1994). In this study, repetitions equaled the combined number of eccentric contractions and eccentric actions.

METHODOLOGY

Subjects

23 university aged males (21-29yr) experienced in resistance training were recruited to serve as volunteers for this project. "Experienced in resistance training" was defined as subjects who were following a resistance training program for a minimum of twelve successive months and who demonstrated the ability to lift 1.0 kg/kg of body weight while performing a bench press. Complete explanation of testing and training procedures was provided prior to obtaining written informed consent and participation in this study. Subjects satisfying the above criteria were randomly assigned to either a submaximal intensity training group (n = 11) or a supramaximal intensity training group (n = 12). Submaximal intensity training is the training level conventionally used by athletes and was considered as the control group (CV). The supramaximal intensity training group was referred to as the experimental group (SME). Five subjects (1 from the CV group and 4 from the SME group) failed to complete the training.

Training

Training persisted for nine weeks, initially at a training frequency of 2 sessions per week for 2 weeks and then 3 sessions per week thereafter. The muscle groups that were trained included the forearm flexors and extensors. Each training session was comprised of two core exercises to train the two specific muscle groups. Seated bilateral biceps curl was performed utilizing a preacher curl bench and a curling bar. Bilateral triceps extensions, executed in a supine position with a curling bar, was the second exercise. The order of performance for the two core exercises was randomized from session to session.

Supplemental exercises, targeting other major muscle groups were completed after the core exercises or on separate training days. Three sets of approximately 10-12 repetitions of the supplemental exercises were performed. The control group trained at approximately 75% concentric 1RM. Subjects in this group performed 4 sets of 10 repetitions (to concentric failure). Training intensities of the experimental group alternated between eccentric and concentric actions within each set. Experimental group subjects performed 3 sets of 10 repetitions (to concentric failure). Eccentric contractions were executed at an intensity of 110-120% concentric 1RM. As this intensity was greater than concentric 1RM it was referred to as supramaximal. Concentric contractions were performed at 75% concentric 1RM. Training supervisors or partners adjusted the training load at the end of each contraction (eccentric or concentric) to ensure proper intensity levels for each subsequent contraction (concentric or eccentric). Training was rate-controlled for both groups so that each eccentric and concentric contraction lasted approximately 2 seconds. Although training intensity differs between groups, training volume (sets x [(concentric reps x concentric load) + (eccentric reps x eccentric load)]) was equated. Subjects in the control group averaged 59 volume units of work per set while the experimental group performed 58 units per set. Rest periods of 3 minutes were mandatory for all subjects between each training set. A minimum of 48 hours rest was required between workouts for all subjects. As training progressed, loads were monitored and altered to ensure the training repetitions were maintained. When the average number of repetitions performed per set per training session reached greater than 10, subjects were instructed to increase the training load. A minimum of one training session per week was supervised to confirm correct procedures and loads were utilized during training. In a training diary, subjects recorded training load, number of repetitions performed during each training session and level of muscle soreness over the duration of the study. A subjective pain scale (1 representing no pain, 2 equaling pain with movement, 3 representing pain with deep touch and 4 representing constant pain) was utilized to monitor level of muscle soreness.

Testing

Evaluation of muscle strength, muscle cross-sectional area and specific tension occurred pre-training (test 1) and post-training (test 4) of the nine weeks of resistance training. Strength was also evaluated mid-training at both 3 (test 2) and 6 (test 3) weeks.

Strength

Strength testing was conducted with 72 hours of rest from the most previous training session. Concentric and eccentric strength of the forearm flexors and forearm extensors was assessed through performance of seated bilateral biceps curls and supine triceps extensions, respectively. Maximal concentric strength (concentric 1RM) was the maximum resistance a muscle could overcome while shortening during a maximal voluntary effort. Concentric 1RM was determined through successive trials of increasing intensity. Magnitude of the load increased (if more than one repetition was performed) or decreased (if less than one repetition was performed) until the load was established when only one contraction could be performed. Eccentric strength was measured as the number of eccentric contractions (repetitions) produced by a muscle at 130% concentric 1RM. To ensure that muscle lengthening was controlled, each eccentric action spanned the range of motion over 4 seconds. A metronome controlled this rate. Failure was established as the second eccentric muscle action that no longer complied with the 4-second rate. Only those repetitions satisfying the above criteria were recorded. A previous pilot study established test-retest reliability as R= 0.81 (intraclass correlation).

Seated bilateral biceps curl, measuring forearm flexor strength, was conducted on a preacher curl bench using a curling bar. Subjects were seated with both feet flat on the floor. The posterior aspect of the subject's arms along with the subject's axillae rested on the preacher bench pad. The height of this pad was adjusted so that each subject's torso was straight. Using an underhand grip all subjects grasped the curling bar at the narrowest width. Initiation of the concentric biceps test occurred from 10 degrees of flexion (0 degree equals full extension). A successful trial was considered when the muscle achieved full forearm flexion (the point of tissue contact between the forearm and biceps).

Forearm flexor eccentric strength was assessed from full flexion until 10 degrees of flexion. Assistance was provided to move the resistance through the concentric phase until failure was reached. Assessment of forearm extensor strength occurred from a supine position on a bench. Subjects were instructed to maintain contact with the bench at the position of the head, shoulder blades, buttocks and thighs. Both feet were positioned flat on the floor. Subjects grasped the curling bar at the narrowest grip using an overhand grip. Concentric 1 RM determination initiated from a joint angle of 100 degrees forearm flexion. The curling bar was held superior to the subject's forehead with elbows being shoulders width apart. A repetition was considered successful when full forearm extension was achieved. The range of motion during the eccentric strength test originated from full forearm extension and ended at 100 degrees of forearm flexion. Assistance was provided to return the resistance to the starting position. Concentric 1 RM appraisal of the forearm flexors and extensors preceded evaluation of eccentric strength. Subjects completed 2 x 10 repetition warm up sets prior to concentric 1 RM. A 4-minute rest period separated all warm up and testing sets. Concentric 1RM tests and eccentric strength tests were separated by 10 minutes of rest.

Cross-sectional Area (CSA)

Measurement of muscle CSA of the forearm flexors and forearm extensors of the right arm was performed through Magnetic Resonance Imaging (General Electric, Signa Horizon, 1.0 T). Relaxation and echo times were set at 525 and 12 ms respectively. The field of view utilized was set at 16 cm^2. Humeral length was established through external measurement (olecranon process to the acromion process). Incorporating this measurement, midpoint of the humerus was determined from the olecranon process that was detectable through a coronal scan. Measurement of the forearm flexors and extensors occurred with the subjects in a supine position with the arm positioned superior to the body. The arm was positioned inside a knee coil to permit enhanced resolution. 12 axial scans were performed, initiating from 70 mm superior to the midpoint. Each scan (slice) was 10 mm thick and separated from the next by 5 mm. Six images (2 proximal to midpoint, 2 at approximate midpoint and 2 distal to midpoint) of the forearm flexors and forearm extensors were traced allowing for determination muscle CSA. CSA of the forearm flexors and extensors was measured as the maximum value of the 6 slices as well as the average value of the 2 proximal, 2 midpoint and 2 distal slices. Images were traced at a constant contrast setting and in a manner so that it was not possible to distinguish between pre and post training images. Each image was traced until three values within 1% were obtained. Intraclass test-retest reliability for repeated CSA measurements (3 tracings of 8 different images) equaled 0.996.

Specific Tension

Specific tension (kg·cm$^{2^{-1}}$) was determined for each muscle group by dividing the concentric 1RM test value (kg) (seated biceps curl and supine triceps extension) by the respective maximal CSA value (cm^2).

Statistical Analysis

Upon completion of the training program, the results for each strength variable were analyzed by two by four (group by time) ANOVAs with repeated measures on the second factor. If any significant results were obtained ($p<0.05$) a series of two by two (group by time) ANOVAs were used to determine at what point differences in strength occurred. Two by two (group by time) ANOVAs with repeated measures on the second factor were performed to identify if the training programs produced group, time and group interaction changes in the specific tension and CSA.

RESULTS

Height, weight and age characteristics of the control and experimental groups are presented in Table 1. No initial differences on any of these dependent variables existed among the two groups prior to training.

Concentric Strength

1 RM measurements of the forearm flexors and extensors are presented in Table 2 and Table 3, as well as Figure 2 and 3 respectively. Forearm flexor and forearm extensor maximal concentric strength increased significantly ($p<0.05$) in response to both CV and SME training. Further, SME training resulted in significantly ($p<0.05$) greater gains in maximal concentric strength of the forearm extensors than CV training. Significant increases ($p<0.05$) in forearm flexor strength of both training groups (from test 1 values) were also observed at test 2 and test 3. No significant differences in forearm flexor strength resulted between the two training groups. Forearm extensor strength of both training groups increased significantly ($p<0.05$) from test 1 to test 2, test 2 to test 3 and test 3 to test 4.

Eccentric Strength

Eccentric strength values of the forearm flexors and extensors are presented in Table 4 and Table 5, as well as Figure 3 and 4 respectively. The number of repetitions performed at a load of 130% concentric 1 RM significantly ($p<0.05$) decreased in the forearm flexors and extensors of both training groups. Significant decrements in forearm extensor performance of both groups, in comparison to test 1, were also observed at test 2 and test 3. At test 3 a significant difference existed between the SME and CV training group as well as within the SME group when compared to test 1($p<0.05$). No other significant differences resulted between the two types of training.

CSA

Maximal CSA measurements for both the forearm flexors and extensors are displayed in Table 6. Proximal, midpoint and distal CSA values for the forearm flexors and extensors are presented in Table 7 and Table 8, respectively. No significant changes in CSA measurements were observed in response to training. Further, no significant differences resulted between the two types of training.

Specific Tension

Values for specific tension of the forearm flexors and extensors are exhibited in Table 9. Both modes of training significantly improved forearm flexor ($p<0.05$) and forearm extensor ($p<0.05$) specific tension. No differences between the two types of training emerged.

Table 1:

Mean (SE) height and weight characteristics of subjects of the CV (N = 10) and SME (N = 8) training groups.

Group	**height (cm)**	**weight (kg)**
SME	179.9 (5.8)	80.4 (2.8)
CV	178.0 (6.2)	81.6 (5.9)

Table 2:

Mean (SE) forearm flexor concentric 1 RM strength values of the CV ($n = 10$) and SME ($n = 8$) training groups pre-, mid- and post -training.

Group	test 1 (kg)	test 2 (kg)	test 3 (kg)	post (kg)
SME	44.2 (5.0)	46.6 (5.4)*	47.5 (4.5)*	48.3 (3.8)*
CV	42.2 (7.0)	45.2 (7.6)*	45.8 (6.7)*	47.0 (6.4)*

Note: * represents significant difference from test 1 (pre-training) value ($p<0.05$).

Table 3:

Mean (SE) forearm extensor concentric 1 RM strength values of the CV (n = 10) and SME (n = 8) training groups pre-, mid- and post-training.

Group	test 1 (kg)	test 2 (kg)	test 3 (kg)	test 4 (kg)
SME	48.8 (7.6)	52.4 (7.5)*	56.5 (8.4)•	60.6 (7.7)**
CV	47.6 (7.5)	50.3 (9.2)*	53.1 (8.7)•	54.7 (9.3)••

Note: * represents significant difference from test 1 value ($p<0.05$).

Note: • represents significant difference from test 2 value ($p<0.05$).

Note: **represents significant difference from test 3 as well as significant difference from CV group ($p<0.05$).

Note: •• represents significant difference from test 3 value ($p<0.05$).

Table 4:

Mean (SE) forearm flexor eccentric strength values of the CV (N = 10) and SME (N = 8) training groups pre-, mid- and post training.

Group	**test 1 (reps)**	**test 2 (reps)**	**test 3 (reps)**	**test 4 (reps)**
SME	4.4 (1.3)	5.1 (1.6)	6.1 (1.9)	3.5 (0.5)*
CV	4.8 (2.1)	4.2 (1.1)	4.0 (1.4)	2.7 (1.3)*

Note: * represents significant difference from test 3 value ($p < 0.05$).

Table 5:

Mean (SE) forearm extensor eccentric strength values of the CV (N = 10) and SME (N = 8) training groups pre-, mid, and post training.

Group	**test 1 (reps)**	**test 2 (reps)**	**test 3 (reps)**	**test 4 (reps)**
SME	4.3 (1.9)	3.4 (1.2)*	2.9 (2.0)*	2.3 (1.0)*
CV	3.5 (1.1)	2.8 (1.4)*	2.8 (1.3)*	2.2 (0.8)*

Note: * represents significant difference from test 1 value ($p < 0.05$).

Table 6:

Mean (SE) maximum forearm flexor and extensor CSA measurements of the CV (N = 10) and SME (N = 8) training groups pre- and post-training.

Muscle	**SME** (cm^2)	**CV** (cm^2)
Forearm flexors		
pre	30.52 (3.64)	28.7 (4.06)
post	30.43 (2.65)	29.6 (4.69)
Forearm extensors		
pre	36.34 (3.81)	35.43 (7.08)
post	36.94 (3.16)	36.03 (7.26)

Table 7:

Mean (SE) summed proximal, midpoint and distal forearm flexor CSA measurements of the CV (N = 10) and SME (N = 8) training groups pre- and post-training.

Site	**SME** **(cm^2)**	**CV** **(cm^2)**
Proximal		
pre	26.1 (4.7)	23.5 (6.6)
post	24.7 (3.1)	23.7 (5.7)
Midpoint		
pre	39.8 (10.1)	35.9 (8.5)
post	39.7 (8.8)	36.2 (7.3)
Distal		
pre	57.7 (8.2)	55.0 (8.2)
post	57.8 (6.4)	56.7 (8.9)

Table 8:

Mean (SE) summed proximal, midpoint and distal forearm extensor CSA measurements of the CV (N = 10) and SME (N = 8) training groups pre- and post-training.

Site	SME (cm^2)	CV (cm^2)
Proximal		
pre	69.6 (7.3)	66.8 (11.7)
post	70.2 (5.0)	67.8 (12.3)
Midpoint		
pre	68.9 (6.7)	67.7 (13.4)
post	69.6 (6.8)	69.0 (14.5)
Distal		
pre	47.4 (5.6)	47.6 (10.0)
post	48.6 (6.3)	49.5 (11.4)

Table 9:

Mean (SE) forearm flexor and extensor specific tension values of the CV (N = 10) and SME (N = 8) training groups pre- and post-training.

Muscle	**SME** **(kg/cm^2)**	**CV** **(kg/cm^2)**
Forearm flexors		
pre	1.46 (0.18)	1.47 (0.14)
post	*1.59 (0.08)	*1.60 (0.12)
Forearm extensors		
pre	1.34 (0.18)	1.36 (0.20)
post	*1.64 (0.16)	*1.54 (0.25)

Note: * represents significant difference from pre value ($p < 0.05$).

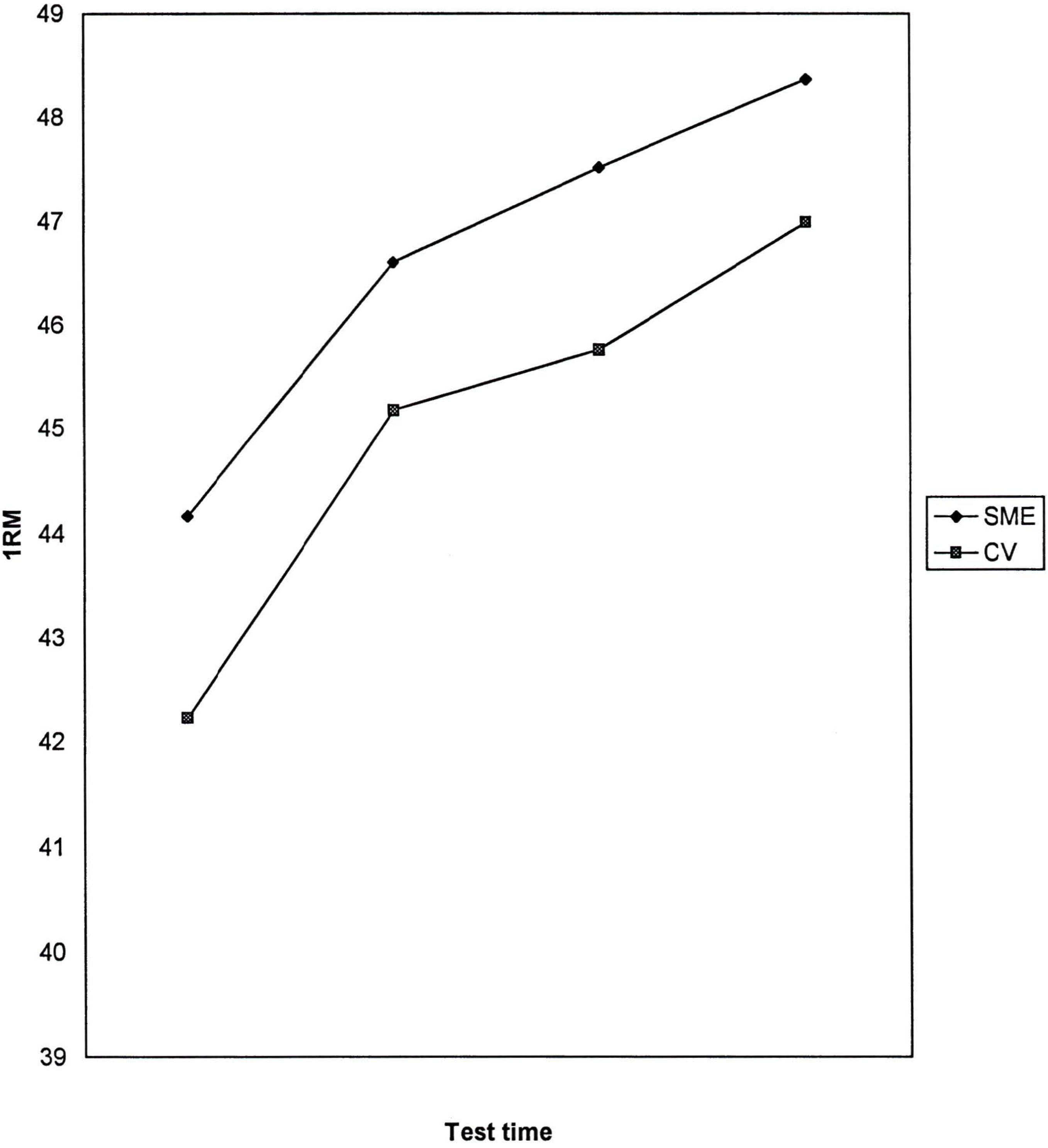

Figure 1

Mean forearm flexor concentric 1 RM strength values of the CV (n = 10) and SME (n = 8) training groups pre-, mid- and post -training

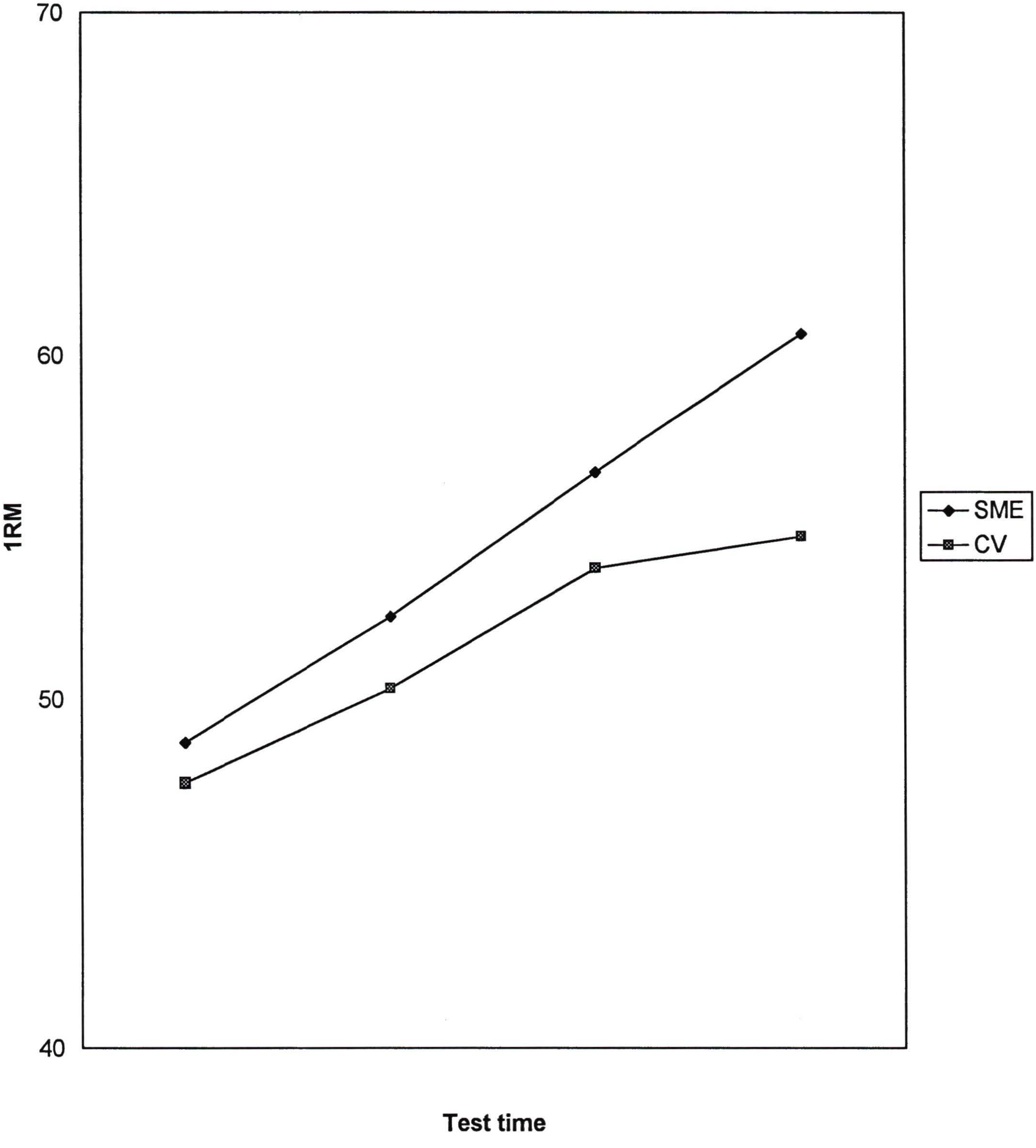

Figure 2.

Mean forearm extensor concentric 1 RM strength values of the CV (n = 10) and SME (n = 8) training groups pre-, mid- and post-training

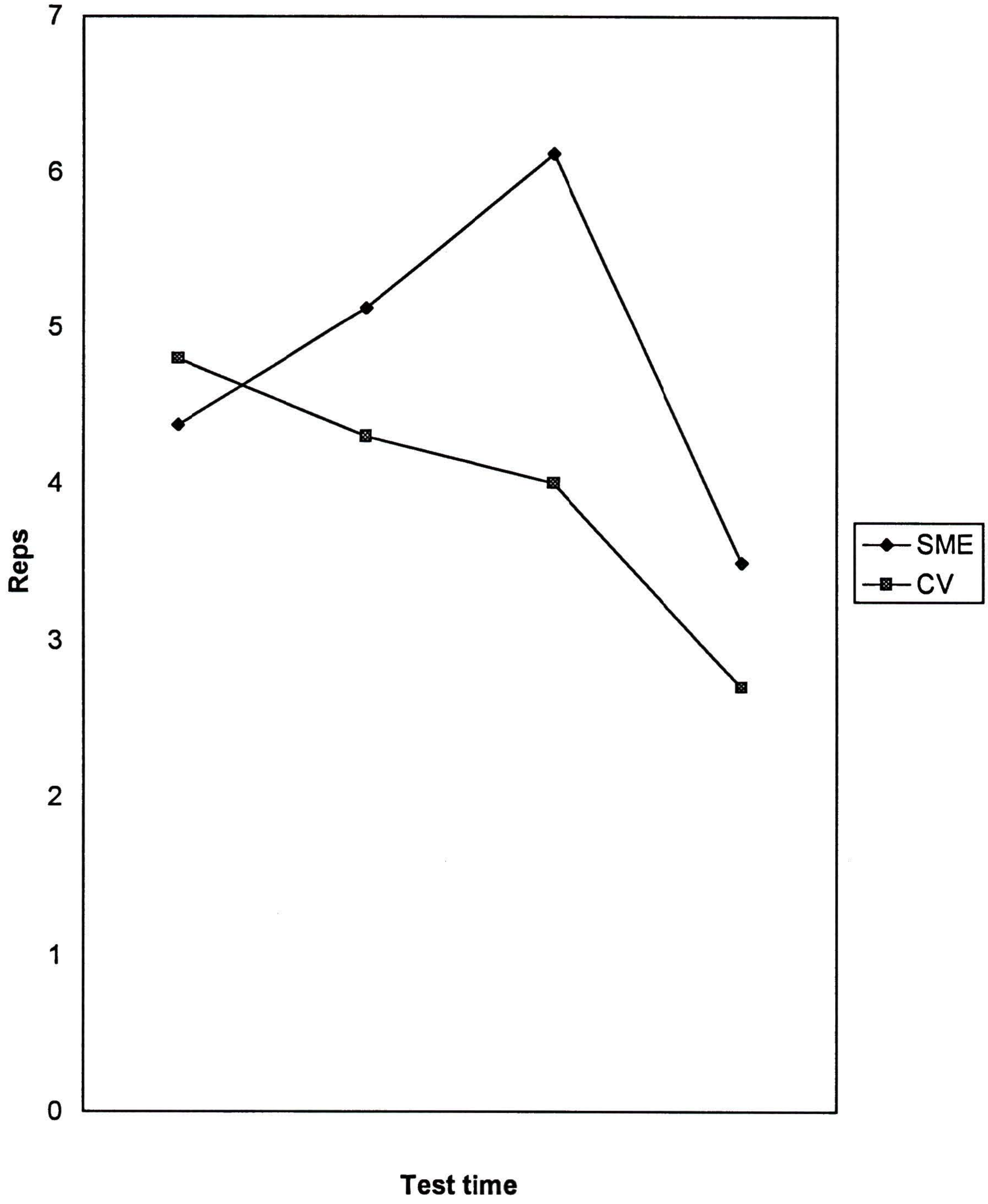

Figure 3
Mean forearm flexor eccentric strength values of the CV (n =10) and the SME (n = 8) training groups pre-, mid- and post training

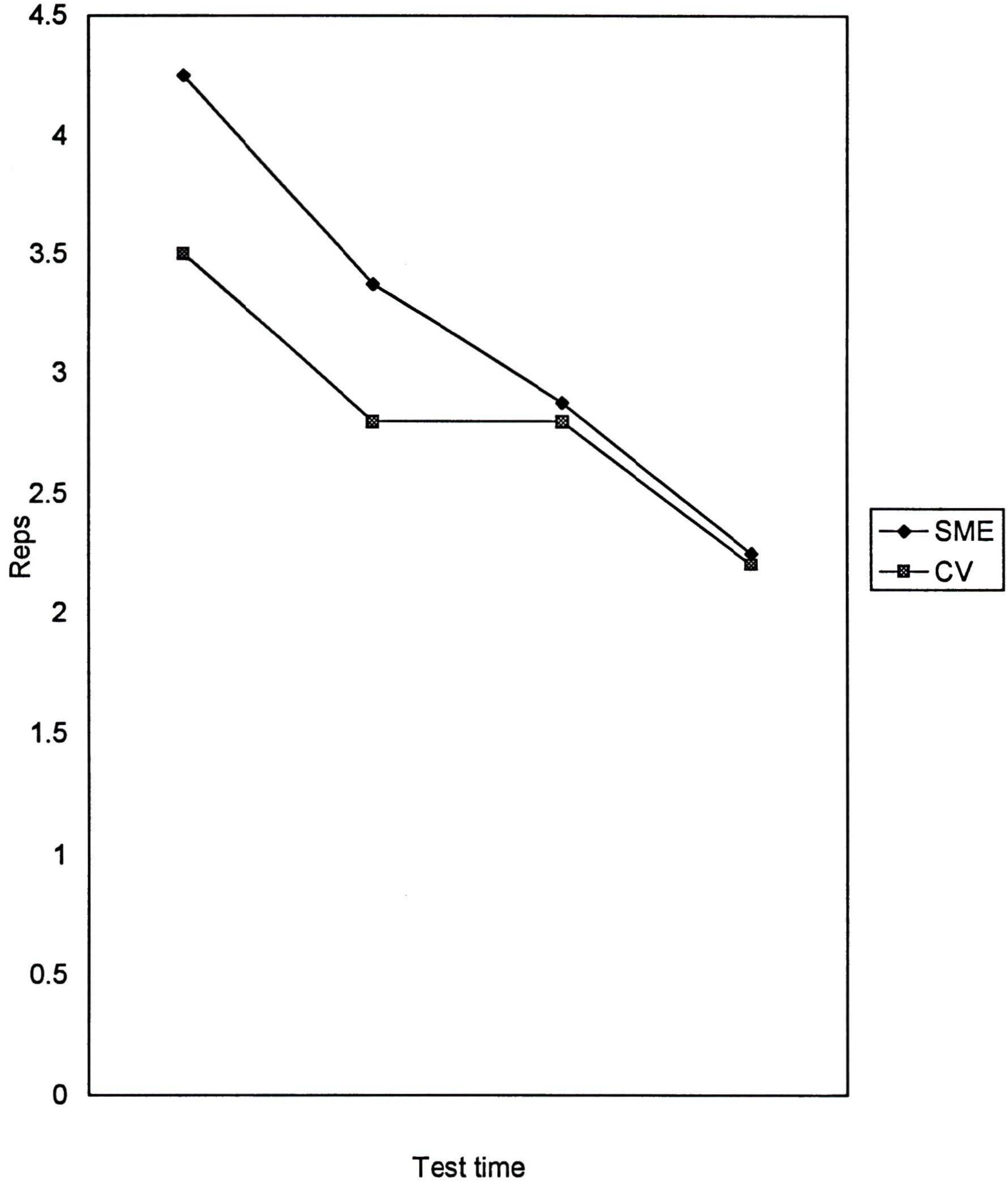

Figure 4

Mean forearm extensor eccentric strength values of the CV (n =10) and the SME (n = 8) training groups pre-, mid- and post training

DISCUSSION

Concentric Strength

The purpose of this study was to compare conventional (CV) resistance training (at a load of 70% concentric maximum for both concentric and eccentric actions) with supramaximal eccentric (SME) resistance training (at a load of 70% concentric 1RM for concentric contractions and 120% concentric 1RM for eccentric actions) on strength and neuromuscular adaptations. It was observed that both types of training elicited significant improvements in forearm flexor and forearm extensor concentric strength. Increments in forearm flexor strength were similar in response to both types of training (Table 2, Figure 1). Supramaximal training, however, produced significantly greater increases in forearm extensor strength than did conventional training (Table 3, Figure 2).

The improvements in strength (14% and 17% for the forearm flexors and extensors of the CV group and 12% and 29% for the forearm flexors and extensors of the SME group) were comparable to other studies of similar duration, utilizing trained subjects. Wilson, Murphy & Giorgi (1996) observed 12% and 21% increases in maximal bench press and squat exercises, respectively, after 8 weeks of heavy resistance training. 10 weeks of 6-10 RM training of the quadriceps produced a 21.5% improvement in isometric strength (Wilson, Newton, Murphy & Humphries, 1993). 8 weeks of training, at loads greater than 90% concentric maximum improved shot put strength by 14.8% (Schmidtbleicher & Haralambie, 1981).

To date no other studies, investigating the effects of concentric coupled to supramaximal eccentric contractions exist. Hakkinen & Komi (1981) and Hakkinen, Alen & Komi (1985) supplemented traditional strength training as well as concentric strength training with supramaximal eccentric actions at intensities between 100 and 130% concentric maximum. Bench press and squat strength increased by 19% and 29%, respectively, following 12 weeks of training composed of 50% concentric and 50% eccentric exercises. However, when 75% of the exercises were performed eccentrically at a supramaximal intensity, strength gains were reduced (Hakkinen & Komi). In response to 24 weeks of heavy resistance training interspersed periodically with supramaximal eccentric training, isometric strength of the quadriceps increased by 26.8% (Hakkinen, Alen & Komi). The strength improvements experienced by the CV and SME training groups are comparable with the findings of these studies despite utilization of a shorter training period.

The magnitude of improvement in concentric maximal strength of the forearm extensors was single difference between the two types of strength training (Table 3, Figure 2). Although equal concentric training intensities of the CV and SME training groups, improvements in concentric 1RM were greater for the SME training group. Utilization of supramaximal loads during eccentric actions enhanced concentric strength, implying that strength gains are not specific to the type of muscle action performed in training (Morrissey, Harman, & Johnson, 1995). Similarly, it was previously revealed that supramaximal eccentric training, performed without concentric actions, improved maximal concentric strength (Ben-Sira, Ayalon & Tavi, 1994).

The observed strength results may be explained by neural recruitment patterns of muscle. Recruitment of motor units is graded and dependent on the magnitude of resistance applied to a contracting muscle (Sale, 1988). Because of the greater training loads, SME training may have resulted in the recruitment of more muscle fibers than CV training. Consequently, muscle tension would have been experienced by more fibers, possibly accounting for the differences in triceps strength gains between the two groups. Selective recruitment may offer an explanation to why the same strength improvements were not observed with the forearm flexors. Evidence suggests that selective recruitment of motor units may occur in a muscle responsible for multiple actions (Sale, 1992). The biceps brachii is involved in flexion as well as supination of the forearm (Sale). During flexion of the forearm, the lateral portion of the biceps is active, while the medial aspect of the biceps is recruited during supination (Sale). Forearm flexion was the exercise exclusively performed by the biceps brachii in this study, potentially limiting the number of fibers exposed to activity. With a limited number of fibers to recruit from, the difference in training loads between the CV and SME groups may not have produced different levels of recruitment, possibly accounting for the lack of observable differences between these groups.

MacDougall (1992) discovered that the percentage of fast twitch motor units is greater in the triceps brachii then in the biceps brachii. Recruitment during eccentric actions appears to preferentially activate fast twitch motor units (Nardone, Romano & Schieppetti, 1990), which are more responsive to neuromuscular adaptations

(MacDougall). The greater number of fast twitch fibers in the triceps may account for the strength differences in the triceps and lack of differences in the biceps muscle group in response to SME and CV training.

The differences in improvement between the forearm flexors and extensors may possibly be accounted for by muscle size. Hakkinen and Komi (1981) observed different magnitudes of improvement in different muscle groups despite equal training intensities (19% for bench press and 29% squat). In the present study, improvements were greater for the SME training group then for the CV training group in terms of maximal concentric strength of the forearm extensors. Triceps, like the quadriceps muscle group, has a larger muscle volume and CSA than the biceps and pectoralis muscle groups respectively. Consequently, a larger amount of contractile content may have been exposed and therefore adapted to the training. Further, the triceps brachii is a pennate muscle designed for development of high forces. In a pennate design, muscle fibers attach to the tendon at a certain angle of pull permitting greater contractile elements to attach to a limited area (Kawakami, Abe, Kuno & Fukunaga, 1995). Pennation angle determines the angle of pull of a muscle, in relation to the movement direction, and is therefore considered an important determinant of force output. If load applied to the musculature is a stimulus for strength adaptations, perhaps this arrangement in addition to a greater CSA, facilitated the high loads encountered by SME training, partially accounting for the differences produced in concentric strength of the triceps. Alternatively, angle of pennation of the quadriceps has been demonstrated to increase following resistance training (Rutherford & Jones, 1987). This effect, by altering the angle of pull, may have been responsible for enhancing the force transmission of the quadriceps. A similar change in angle of pennation of the triceps may explain the observed strength changes.

Initial training state of an athlete influences the magnitude of improvement: The more elevated the training state the smaller the gains (Moritani, 1992). Further, a genetic upper limit of neuromuscular adaptation also appears to limit strength gains. Tesch (1992) has suggested that some muscles remain "underdeveloped" even after training. If triceps musculature possessed an inferior state of training than the biceps, it is plausible that the SME training proved effective as a stimulus, explaining the extent of differences noticed between training groups.

Eccentric Strength

Eccentric strength of the forearm flexors and extensors, as measured in this study, decreased from pre-training to post-training in both training groups (Table 4 & 5, Figure 3 & 4). Although pre-training to post-training decrements in eccentric performance were observed in both muscle groups, the pattern of change was different. Forearm extensor eccentric strength, in both training groups, showed a consistent and gradual reduction over the duration of training (Table 5, Figure 4). Altogether, there was a significant reduction in the number of eccentric repetitions performed from pre-training to post-training in both training groups. Despite sharing a similar pre-training to post-training decrease as the forearm extensors, the pattern of change for the forearm flexors of the SME group was different. Prior to experiencing a decrease in eccentric performance, the forearm flexors of the SME group demonstrated improvements in eccentric strength up to test 3 (Table 4, Figure 3). The increases were large enough to be significantly greater than pre-training values as well as significantly greater than values of the CV group at the same test period.

The decrease in the number of eccentric repetitions performed may be attributed to an actual decrease in eccentric strength or the method that was used to assess eccentric strength. Eccentric strength was measured as the number of repetitions performed at a load of 130% of concentric maximum. Because concentric strength increased in both training groups, so did the absolute load used to evaluate eccentric strength. Thus, the observed decrement in the number of repetitions performed at a load of 130% concentric 1RM may be a result of the greater absolute load encountered during testing instead of a decrease in eccentric force production.. If the absolute testing load remained constant throughout the testing periods, an increase rather than a decrease in repetitions performed may have been observed. Furthermore, forearm flexor and extensor 10RM training load for eccentric actions increased over the duration of the study. The supramaximal eccentric training load at which 10 repetitions could be performed increased 18% and 22% for the forearm flexors and extensors, respectively, in the SME group. The 10RM training load for the CV group increased 14%.

An eccentric strength deficit, rather than a reduction in eccentric force production may offer an alternate explanation for these results. Field tests, investigating the number of repetitions capable at 90% of concentric maximum have been utilized to determine whether maximal force is limited by neuromuscular mechanisms (Wilson, 1995). The increases in absolute load exposed to forearm flexors and extensors during eccentric strength testing may have stimulated inhibitory mechanisms. Stimulation of the Golgi Tendon Organ in response to high levels of muscle tension, results in inhibitory signals limiting the number of motor units activated as well as the firing frequency producing a reduction in force generated (Wilson). A decrease in the number of repetitions performed may also be evidence of a reduction of the concentric strength deficit. Concentric strength deficit, by assessing the percentage difference between absolute force and maximum voluntary force capabilities, ascertains the extent to which available musculature can be voluntarily activated (Schmidtbleicher, 1985; Tidow, 1990). Absolute strength, often evaluated under eccentric actions utilizing a supramximal load, represents the complete force potential of muscle. Conversely, maximal force attained under voluntary conditions is inhibited through neural mechanisms (Tidow; Wilson, 1995). The increases in concentric 1RM may indicate a greater use of the forearm flexors and extensors force potential, lessening the difference between absolute and voluntary force capabilities, and accounting for the decrease in the number of eccentric repetitions performed at 130% concentric 1RM rather than a reduction in eccentric strength. Wilson (1995) identifies disinhibition as a contributing factor to minimizing the strength deficit. Exposure of a muscle to high levels of tension may decrease the sensitivity of inhibitory mechanisms in a process termed disinhibition (Wilson). Disinhibition, would permit a greater recruitment of motor units and a higher firing frequency of activated units which would increase voluntary force production. Additionally, the contractile content of the forearm flexors and extensors did not significantly increase possibly compromising gains in the contractile potential of the muscle thus limiting absolute force production

Resistance training is believed to alter the compliance of the elastic properties of muscle (Zernicke & Loitz, 1992). Evidence suggests that a stiff muscle, through more effective transmission of forces to the bone-lever system during muscle shortening, enhances concentric performance but not eccentric force production (Wilson, Murphy & Pryor, 1994). If the resistance training protocols altered the compliance of forearm flexors and extensors, this change may account for the decrease in eccentric strength performance.

Although the forearm extensor eccentric strength of the CV and SME training groups followed a similar trend (Table 5, Figure 4), eccentric strength values of the forearm flexors of the SME training group increased up to week 6 before experiencing a decline (Table 4, Figure 3). At week 6, the SME group performed a significantly greater number of eccentric actions when compared to pre-training as well as the CV group. These results may suggest that training with eccentric loads between 110-120% of concentric 1 RM may have permitted development of a learning effect specific to the type of training and training load experienced (Sale, 1992). Post-training values of the forearm flexors of the SME group, along with the CV training group were significantly reduced in comparison to pre-training measures (Table 4, Figure 3). Forearm pain, experienced by most subjects late in the training period may explain the decline in eccentric performance of the forearm flexors. "Neural fatigue", associated with reduced muscle performance, may be evident with periods of constant and intense training (Baker, Wilson & Carylon., 1994). A reduction in the ability of a muscle to sustain a contraction or to repeatedly contract has been defined as fatigue (Hakkinen, 1994). The increments in absolute load for testing eccentric strength combined with the 4-second rate of action may have accelerated the onset of fatigue, accounting for the decrements in reduction of eccentric repetitions performed. Additionally, residual fatigue from training, as measured as a decrease in maximum force output, has remained for as long as 10 days in untrained subjects upon completion of supramaximal resistance training (Saxton et al., 1995). Unloading periods, of rest or less intense training, may have alleviated forearm pain and possible fatigue, potentially benefiting eccentric strength performance. Gibala, MacDougall and Sale (1994) demonstrated that isometric and dynamic strength responded positively to an 8 day reduced volume training period

In the only available study testing eccentric strength at a similar load, Wilson, Murphy and Giorgi (1996) investigated the ability to eccentrically resist an accelerating mass of 130% concentric maximum. 8 weeks of 6-10 RM resistance training provided no significant advantage for the upperbody in performing the above task. No improvements were observed post plyometric training, which like SME training, involves a large eccentric component.

Muscle CSA

Although the number of repetitions performed by both training groups fell in the proposed range for hypertrophy (Tesch, 1992), neither type of training induced a significant hypertrophic response in maximum (Table 6), proximal, midpoint or distal CSA of the forearm flexors (Table 7) or extensors (Table 8). One explanation may be the pre-training condition of the subjects. Moritani (1992) has suggested that hypertrophy is limited in individuals experienced in resistance training. Throughout a one year training period, elite power lifters increased strength without simultaneous gains in muscle CSA (Hakkinen, Alen, Komi & Kauhanan, 1987). Similarly, over a two year period, elite weight lifters exhibited minimal increases in mean fiber area of the quadriceps (Hakkinen, Pakarinen, Alen, Kauhanen & Komi, 1988). However, these observations may have been a result of the type of training performed (high intensity, low volume) rather than training state. Furthermore, muscle fiber area of bodybuilders did not exceed that in subjects who had only trained for several months, suggesting a ceiling size for cross-sectional area may exist (MacDougall, Sale, Elder & Sutton, 1982). Contrary to these results, Hakkinen, Alen & Komi (1985) observed selective fast twitch muscle fiber hypertrophy in trained individuals during the initial 12 weeks of a 24 week heavy resistance (concentric combined with eccentric) training program. Hypertrophy, however, was negligible during the final 12 weeks. Increases in thigh girth were significant after 12 weeks utilization of a similar training program as the aforementioned study (Hakkinen & Komi, 1981).

It is possible hypertrophy may have occurred without measurable increases in muscle CSA. Goldspink (1992) has proposed that muscle fiber hypertrophy is possible without measurable increases in whole muscle CSA. An increase in fiber girth would result in a reduction of extracellular space surrounding the fibers, leading to a denser but not larger muscle. Using untrained subjects, density of the quadriceps muscle significantly increased after 12 weeks of training only eccentrically at a load of 145% concentric maximum (Jones & Rutherford, 1987). Likewise, myofibrillar density of muscle fibers may increase, elevating the number of cross-bridges acting in parallel while muscle fiber size remains unchanged (Fitts & Widrick, 1996). Conversely, it was revealed that subjects who had only trained for 6 months exhibited a similar packing density as bodybuilders who had trained for years (MacDougall, Sale, Elder, & Sutton, 1982).

Another explanation for the lack of observable hypertrophy may be in the method used for determining muscle CSA. In the present study CSA was measured as the maximal CSA slice perpendicular to the length of the humerus. However, determination of maximum CSA of a muscle or muscle group depends on orientation of the muscle fibers (Roy & Edgerton, 1992). As the triceps muscle group possesses a pennate design, the fibers are not arranged parallel with the humerus, thus the perpendicular scan may have not provided a true indication of forearm extensor CSA. An increase in myofibrillar content would have occurred along the pennate orientation. Accordingly, hypertrophy of the forearm extensors may not have been detectable with the present method of CSA measurement. Kawakami, Abe, Kuno and Fukunago (1995), however, observed increases in maximum CSA of the forearm extensors using similar CSA measurement methods of the present study. Further, an increase in the amount of myofibrillar content of the triceps muscle could alter the angle of pennation (Fitts & Widrick, 1996). Alterations in the angle of pennation may have the effect of enhanced force output.

The training volume necessary to elicit a hypertrophic response in trained individuals must be of significant magnitude to adequately stimulate muscle tissue growth (Kraemer, Fleck & Evans, 1996). Perhaps the volume of training performed by the SME training and CV training was not large enough to increase muscle CSA. However, the training programs incorporated by studies demonstrating hypertrophy (Hakkinen & Komi, 1981; Hakkinen, Alen & Komi, 1985) were of a lower training volume than the present study.

The time course of adaptations to new exercises predominately involves initial neural adaptations with hypertrophy ensuing (Sale, 1992). Initial evidence for this concept was provided by Hakkinen, Komi and Tesch (1981) when they observed that hypertrophy of the leg extensors did not occur until the final eight weeks of 16 weeks of high intensity (concentric combined with eccentric contractions) training. If the core exercises performed in the present study were unfamiliar to the subjects at the onset of training, 9 weeks may not have been of sufficient duration to observe increases in muscle CSA.

Selective recruitment of subpopulations of motor units was previously mentioned as a factor contributing to the equal improvements in biceps strength. Selective recruitment may also explain the lack of measurable hypertrophy in the biceps. Perhaps hypertrophy occurred in those fibers of the lateral portion of the forearm flexors that were regularly activated during forearm flexion. Alternatively, those fibers not involved in forearm flexion may have atrophied as a result of inactivity, thus negating measurable gains in hypertrophy.

Eccentric-induced muscle damage, a result of eccentric contractions, is associated with delayed onset of muscle soreness. Soreness due to maximal eccentric resistance training has been demonstrated to peak 3 days post training (Saxton et al., 1995). Muscle damage has been mentioned as a possible stimulus for hypertrophy, however if the frequency of training is greater than the time course of recovery from eccentric induced damage the muscle may be in a constant state of breakdown. If this is the case, the trained muscle may not have had the opportunity to build. Gibala, MacDougall and Sale (1994) discovered that trained athletes respond positively, with regards to muscle performance, with the implementation of a low volume phase in the training period. A 10 day reduced volume training phase, which progressively reduced the number of sets performed, improved isometric and low velocity force output of the forearm flexors. This period may permit the muscle too completely adapt to training stresses, potentially enhancing contractile performance (Gibala, MacDougall & Sale). Alternatively, muscle soreness (as measured by a subjective pain scale) diminished as training prolonged. These findings support observations of eccentric training on a treadmill reducing delayed onset of muscle soreness (Balnave & Thompson, 1993). If hypertrophy is an adaptation stimulated by muscle damage, increases in muscle CSA may have been absent since muscle soreness (damage) was only observed during the initial weeks of training.

High force eccentric contractions place strain on connective tissue around and within the muscle (Stone, 1992). Increased serum markers of connective tissue breakdown have been observed following eccentric exercise (Stone). It is possible that training produced an effect on connective tissue resulting is more efficient transmission of forces, accounting for the increases in observed strength (Zernicke & Loitz, 1992). The extent to which an increase in the amount of connective tissue would influence muscle CSA should be considered minimal (MacDougall, 1992). The addition of connective tissue may also influence muscle elasticity or compliance. A more stiff musculoskeletal unit, has been demonstrated to enhance concentric force production but not eccentric force production (Wilson, Murphy & Pryor, 1994).

Specific Tension

The force generating capacity per unit of muscle area is referred to as specific tension. Specific tension has been reported to increase as a result of resistance training (Davies et al, 1988; Narici, Roi, Landoni, Minetti & Cerretelli, 1989). Additionally, strength trained athletes exhibited significantly greater specific tension values than endurance athletes (Hakkinen & Keskinen, 1989). Specific tension of the forearm flexors and extensors significantly increased in response to both types of training performed in the present study (Table 9). The differences between the magnitude of improvements elicited by CV training and SME training were not significant for either of the muscles trained (Table 9).

Significant improvements in specific tension of both the forearm flexors and extensors were evident in response to SME and CV training. It is believed that an increase in specific tension is attributed to neural adaptations or an increase in neural drive. Sale (1992) suggested that acquiring the coordination necessary to effectively perform an exercise is the predominating neural adaptation during the first several weeks of training with an unfamiliar exercise. If the subjects were unaccustomed to the core exercises, acquisition of coordination may account for similar improvements in specific tension. During this time, increases in force output may result from intermuscular coordination, or synchronization, where by all the muscles involved in a movement learn to cooperate in the intended movement (Scmidtbleicher, 1992).

Training at high loads requires the recruitment of all or most motor units as well as for all recruited motor units to retain a high firing frequency (Sale, 1992). On account of the training loads utilized during SME training, recruitment and firing frequency of motor units may have been greater than CV training. Sale (1992) has postulated that neural adaptations, such as the ability to increase the firing frequency of a motor unit, require an extended training period. SME and CV training differences in forearm extensor specific tension were approaching significance at the nine week point. Thus, the training period of nine weeks may not have been of sufficient duration discern differences in specific tension improvements between training methods.

Hakkinen, Alen and Komi (1985) observed that strength increases, occurring during the most intensive training periods of a 24 week strength training study, were associated with an elevated iEMG. Eccentric training at loads equaling 100-120% of concentric maximum were incorporated during the periods of intense training. Comparable iEMG and strength responses were observed in elite powerlifters during a 1 year training period (Hakkinen, Alen, Komi & Kauhanan, 1987). Decrements in iEMG that occurred during periods of the lowest training intensity (77.1% of maximum) while periods of slightly higher training intensities (79.1%) elicited significant increases in iEMG. From these findings, it was concluded that training intensity is a critical regulator of neural activity in trained individuals. Results of the present study contradict this conclusion, as SME training failed to elicit significantly greater neural adaptations (specific tension) than CV training in trained individuals.

Training rate for both the SME and CV training groups was controlled at 2 seconds per concentric action and 2 seconds per eccentric action. Evidence has indicated that during prolonged submaximal contractions, recruitment of previously inactive motor units occurs as activated motor units fatigue and no longer generate force (Garland, Enoka, Serrano & Robinson, 1994). If contraction rate was slow enough to produce this effect, any advantage in the amount of recruitment maintained by SME training would have been countered, potentially accounting for no observed differences as a consequence of either training type. This effect may be magnified in the forearm flexors, where selective recruitment may already limit the number of muscle fibers available for activation.

CONCLUSIONS

Greater improvements on strength, muscle CSA and specific tension were anticipated in response of SME training compared to the response of CV training. Support for this hypothesis was only provided in the concentric 1RM increases of the forearm extensors. Even though forearm flexor concentric 1RM increased, no other differences were evident between the training groups. Increases in concentric 1RM may be attributed to neural adaptations as specific tension increased while muscle CSA remained constant. However, with the method used to assess muscle CSA combined with the architecture of the forearm extensors, muscle hypertrophy may not have been observed. Eccentric strength, as measured in this study, decreased from pre-training to post-training. An increase in the absolute load from the pre-training test to the post-training test, rather than a decrease in eccentric force output may explain these results. Further, it was observed that the eccentric strength of the forearm flexors increased before experiencing a decrease. These findings may suggest that supplementation of supramaximal intensity training with unloading periods may be necessary to assist muscle recovery and adaptation. As differences in forearm extensor concentric strength emerged between the training groups, further investigation, concerning how muscle architecture and composition influence muscle trainability is warranted.

Directions for future research

1. Some difference in the muscle groups' responses to training existed. The two muscle groups used in this study differ in design. The forearm flexors are fusiform where as the forearm extensors are multipennate. What is the effect of muscle architecture or

muscle fiber composition on trainability? What effect does muscle architecture or muscle fiber composition have on the loading parameters of training?

2. It was expected that the preferential recruitment of fast twitch muscle fibers (Nardone, Romano and Schiepatti, 1989), resulting from the SME training, would have elicited hypertrophy. The lack of hypertrophy observed may indicate that fast twitch muscle size may be near its "ceiling" in individuals experienced in resistance training. What are the effects of a training program that preferentially stimulates slower muscle fibers on muscle CSA of well trained individuals?

3. Some of the results observed in this study may be due to an insufficiency in recovery and adaptation time. What effect does unloading periods, during intense training, have on muscle strength and hypertrophy?

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APPENDIX A

Review of Literature

INTRODUCTION

Strength is defined as the peak force or torque a muscle or muscle group can generate during a maximal voluntary contraction (Knuttgen & Kraemer, 1987; Goldspink, 1992) at a given velocity (Komi, 1992). The magnitude of force produced by a muscle is dependent on the performance of the neuromuscular system (Sale, 1988, 1992; Moritani, 1992). Neuromuscular performance is determined by the quantity (muscle cross-sectional area), the quality (muscle fiber type) and the degree of neural activation (recruitment) of the contracting muscle (Sale; Moritani). Improvement of strength can be accomplished through repeated stimulation of the neuromuscular system by resistance training programs. Adaptation of the neuromuscular system to resistance training occurs through neural mechanisms, muscular mechanisms or a combination of both (Moritani & DeVries, 1979; Sale 1987, 1988). The type, magnitude and time course of these neuromuscular adaptations is influenced by pre-training status as well as the type, duration and intensity of training (Hakkinen, Alen & Komi, 1985; Komi 1986).

MUSCULAR ADAPTATIONS

The main function of muscle fibers, which comprise whole muscle, are to generate force (Billeter & Hoppeler, 1992). Muscle fibers contain myofibrils, which are an arrangement of sarcomeres joined in series (Billeter & Hoppeler; Goldspink, 1992). Sarcomeres, the contractile components of muscle fibers, are composed of myosin (thick) and actin (thin) filaments (Billeter & Hoppeler; Goldspink). During excitation, depolarization of the muscle cell results in a rise in intracellular calcium, allowing for interaction between actin and myosin filaments. Muscle shortening (concentric contraction) occurs when the thin filaments are pulled over the thick filaments (Billeter & Hoppeler; Edman, 1992). Tension developed, which permits the sliding motion of the filaments, is generated by the formation of actin-myosin cross-bridge attachments within the region of overlap between the thick and thin filaments (Edman). Each cross-bridge is an independent generator of force (Goldspink, 1992; Huijuing, 1992); therefore the magnitude of force generated by a muscle is dependent on the number of cross-bridges formed in parallel (Goldspink; Huijuing). As muscle cross-sectional area increases so does the potential for the formation of cross-bridges in parallel. Thus, the maximum force a muscle can achieve is directly related to muscle cross-sectional area (Goldspink; Roy & Edgerton, 1992).

Skeletal muscle is a dynamic tissue capable of increasing in size in response to resistance training (MacDougall, 1992). Muscular hypertrophy, defined as an increase in the size of a muscle, appears to result from a compensatory growth process stimulated by muscular activity (Goldberg, Etlinger, Goldspink & Jablecki, 1975). Hypertrophy in response to resistance training has been well established (Moritani & DeVries, 1979; Hakkinen, Alen & Komi, 1985; Narici, Roi, Landni, Minetti & Cerretelli, 1989; Garfinkel & Cafarelli, 1992). Mechanisms of hypertrophy include (a) an increase in muscle fiber size (Goldberg et al.), (b) an increase in interstitial connective tissue (MacDougall, 1992; Stone, 1992) and possibly (c) an increase in muscle fiber number (hyperplasia) (MacDougall, 1984).

Hypertrophy, as a consequence of an increase in muscle fiber size, is attributed to an increase in the amount of myofibrillar content within each muscle fiber (Goldspink, 1992). Protein metabolism seems to be altered, producing an increase in protein synthesis and a decrease in protein breakdown (Goldberg et al., 1975). Resistance training stimulates the addition actin and myosin filaments to the periphery of the myofibrils creating a larger myofibril and increasing the myofibrillar content of the exercised muscle fiber (MacDougall, 1992). MacDougall (1992) has suggested that myofibrillar splitting occurs, causing an increase in the number of myofibrils and thus increasing myofibrillar content. An increase in myofibrillar content, producing an associated increase in muscle CSA, has the physiological implications of elevating the contractile force of the muscle fibers and whole muscle (Komi, 1986).

Contractile force of a muscle is also dependent upon the muscle fiber composition of the muscle (Sale, 1987). Based on functional and metabolic qualities, muscle fibers have been categorized into larger, fast twitch fibers (IIA and IIB) and smaller, slow twitch fibers (I)(Sale). Due to a large amount of myofibrillar content they contain, fast twitch fibers are larger and maintain a greater ability to generate force than slow twitch fibers. Evidence also demonstrates that fast twitch muscle fibers are more responsive to hypertrophy than slow twitch muscle fibers (Hakkinen, Alen & Komi, 1985). As fast twitch fibers have an elevated force generating capacity when compared to slow twitch fibers, this "hyper-responsiveness" for growth will lead to further gains in muscle force production. Transformation of muscle fiber subtypes appears to be a response to heavy resistance. Protocols combining concentric and eccentric contractions elicited a reduction in IIB content with a concomitant increase in IIA content (Dudley, et al. and Hather et al.).

Resistance training also seems to induce adaptations in connective tissue. Connective tissue, formed from collagen, exists around and within muscle (Stone, 1992). Connective tissue participates in the transmission of forces from the muscle to the bone-lever system in addition to providing supportive strength (Stone, 1992). Jones & Rutherford (1987) suggest that collagen synthesis may increase as a result of resistance training. New collagen deposited within the muscle fibers, forming new attachments between sarcomeres may permit greater tension to be transferred through the sarcomeres thus increasing the force producing potential of the muscle (Jones & Rutherford).

Although hyperplasia has been demonstrated in cats evidence of muscle fiber splitting in humans remains controversial (Komi, 1986).

NEURAL ADAPTATIONS

Neural adaptations are manifested through enhanced muscular strength in the absence of concomitant hypertrophy (Moritani & DeVries, 1979) or when the force generating gains of skeletal muscle exceed associated gains in muscle CSA (Moritani & DeVries, 1979; Narici et al., 1991). Neural adaptations are also evident when unilateral training of one limb results in strength improvements of the untrained contralateral limb (Jones & Rutherford, 1987; Sale 1987, 1988, 1992). Conceivable neural mechanisms responsible for strength enhancement include a) recruitment of a greater number of muscle fibers (Moritani & DeVries; Sale; Narici et al.; Wilson, 1995), b) elevated firing frequency of activated motor units (Moritani & DeVries; Sale), c) more effective synchronization of contracting motor units (Milner-Brown, Stein & Lee, 1975) and d) a reduction of inhibitory or protective mechanisms (Garfinkel & Cafarelli, 1992; Sale; Wilson).

The functional unit of the neuromuscular system is known as the motor unit. A motor unit is comprised of a motorneurone (nerve cell) and the muscle fibers it innervates. Muscles can be composed of few to several motor units. The level of force a muscle can generate is graded and thus dependent upon the number of motor units activated (Sale, 1987). For the greatest possible force all the motor units of a muscle must be activated (Sale, 1992).

Motor units have been classified into slow oxidative (SO), fast oxidative glycolytic (FOG) and fast glycolytic (FG). Furthermore, FOG and FG can been grouped together to form fast twitch fibers while SO is classified as slow twitch. Recruitment of motor units is based on the "size" principle. Recruitment occurs according to size (smallest to largest) as the level of maximal voluntary force increases. Slow twitch (small) motor units, which possess low twitch forces and firing rates, are recruited at a low force level while fast twitch or "high threshold" motor units are recruited at near maximal efforts (Sale, 1992). Reverse order of recruitment, when larger, faster motor units are recruited preferentially over smaller, slow twitch motor units, has been observed during ballistic and eccentric muscle contractions (Nardone, Romano & Schieppetti, 1988 & 1989). Nardone, Romano & Schieppetti (1988), demonstrated that the primarily slow twitch soleus muscle is active during plantar flexion where as the fast gastrocnemii are activated during lengthening contractions. These same researches later observed (1989) that the conduction velocity, action potential amplitude and fatiguabilty of motor units recruited during resisted lengthening of the soleus were characteristic of fast twitch motor units.

Sale (1992), suggests that many untrained athletes are incapable of recruiting the highest threshold motor units. During resistance training, adaptations may develop that improve the ability to activate high threshold motor units, thus achieving enhanced force production(Sale).

Maximal force output of a muscle also requires the motor units to fire (discharge) at a high frequency. Firing frequency refers to the number of nerve impulses muscle fibers receive from a motoneuron of the same motor unit (Sale, 1992). An increase in firing frequency results in an increase in force output by a motor unit. High threshold motor units possess higher discharge rates then low threshold (slow twitch) motor units, therefore possess an increased capability to generate force.

The degree of motor unit activation and firing frequency can be quantified through electromyography (EMG). A direct relationship between the quantity of EMG and force production has been determined (Moritani, 1992). Increases in EMG levels, associated with increased force output, have been demonstrated post resistance training (Moritani & Devries, 1979; Hakkinen & Komi, 1983; Hakkinen, Alen & Komi, 1985; Narici et al., 1991). An increase in the magnitude of the EMG indicates that more motor units have been recruited, the motor units are firing at a higher frequency or a combination of both (Sale, 1992).

Synchronization has been described as the simultaneous firing of active motor units in contracting muscles(Komi, 1986; Sale 1988). Active muscles that coordinate movement include the agonist, synergist and antagonist. The agonist is the prime mover that produces force in the intended direction. Force output of the agonist is assisted by synergist muscles and opposed by antagonists (Sale, 1988). Greater synchronization of motor units has been observed in weight lifters when compared to control subjects (Milner-Brown, Stein & Lee, 1975). Furthermore, the level of motor unit synchronization increased in response to a six week resistance training program (Milner-Brown, Stein & Lee). Although increased motor unit synchronization enhances the rate of force development, it remains unclear whether synchronization enhances peak force (Sale, 1992). Accompanying the contraction of the agonist muscle is a simultaneous contraction of the antagonist muscle (Sale, 1992). Co-contraction of the agonist, the muscle that produces force in the opposite direction of the agonist, would diminish the net torque in the intended direction of movement (Sale). Co-contraction of the antagonist would also result in reciprocal inhibition of the agonist, leading to a further obstruction in force production. Carolan & Cafarelli (1990) have observed that hamstring (antagonist) muscle group coactivation is reduced after training of the quadriceps (agonist) muscle group. Decreased antagonist activity permits complete activation of agonist (Sale) resulting in the potential for elevated force production (Garfinkel & Cafarelli).

The Golgi tendon organ, located within the muscle fiber, responds to high levels of muscular tension. During production of high forces the Golgi tendon organ reflex relays inhibitory impulses preventing maximum motor unit recruitment and maximum firing rates, consequently compromising the expression of maximum voluntary strength (Wilson, 1995). Repetitive exposure of the Golgi tendon organ to high levels of tension, as with resistance training, may reduce the degree of inhibition imposed on the contracting muscle thus increasing the potential to develop force (Wilson).

TIME COURSE AND MAGNITUDE OF ADAPTATIONS

Resistance training produces pronounced and rapid increases in strength which are primarily accounted for by neural factors (Moritani & Devries, 1979; Moritani, 1992). This is followed by a gradual increasing contribution of hypertrophic factors (Moritani & Devries; Komi, 1986, Moritani). Moritani & DeVries, observed that hypertrophic adaptations may occur as readily as 4-6 weeks into a resistance training program. In athletes who perform prolonged strength training, further muscular development is limited (Hakkinen, Alen & Komi, 1985; Hakkinen, Alen, Komi & Kauhanan, 1987; Moritani). At this point in training it is generally accepted that the volume and intensity of training must be substantial to produce further gains in strength (Hakkinen, Alen, Komi, & Kauhanan). Although neural adaptations are thought to terminate or increase at a decreased rate as training progresses, neural associated strength gains have been observed in resistance trained subjects subsequent prolonged high intensity training. Over a two year training period, competitive weightlifters increased strength and power with minimal muscle fiber size changes (Hakkinen et al., 19) During the last 12 weeks of a 24 week resistance training study, training loads of 80-120% of concentric maximum were necessary to increase neural drive as reflected by iEMG levels. Accompanying the increases in iEMG were increases in muscle strength (Hakkinen, Alen & Komi, 1985). To accommodate the resistances greater than 100% concentric maximum eccentric contractions were necessary. Elite power lifters, who trained at high loading intensities (1-3 RM), elicited similar responses (Hakkinen, Alen, Komi & Kauhanan). With trained subjects, Wilson (1993), observed strength increases only in those subjects who trained with heavy loads (80-90% of concentric maximum).

The above results appear to support the belief that the magnitude of the resistance training load is fundamentally important for increasing strength with resistance training (Dudley, Tesch, Miller & Buchanan, 1991). Atha (1981) suggests that the load applied to the musculature is the most important stimulus for enhancing strength. High intensity training with low total training volume however, may not be sufficient enough to induce muscle growth (Kraemer, Fleck & Evans, 1996). Resistance training programs must adequately impose stretch and tension on the contractile units of the muscle (Behm,1995). In doing so, short term protein degradation and long term protein synthesis and remodeling should be promoted, eliciting hypertrophic adaptations. The potential to accommodate the greatest contractile forces occurs during eccentric muscle action (Komi & Buskirk, 1972; Johnson, Adamczyk, Tennoe & Stromme, 1976). Because eccentric contractions can accommodate the highest possible resistances, inclusion of these contractions should produce a more intense training stimulus (Ben-Sira, Ayalon & Tavi, 1995).

PROPERTIES OF ECCENTRIC CONTRACTIONS

An eccentric contraction is defined as the production of force while the muscle is lengthening (Kraemer, 1992). Resisted muscle lengthening while the muscle is activated must be accomplished with an outside force (Billeter & Hoppeler, 1992; Gohner, 1994). It has been postulated that the potential to produce force is 32% greater during an eccentric contraction when compared to a concentric contraction. (Atha, 1981). During muscle lengthening, preferential recruitment exists for type II muscle fibers (Nardone, Romano, & Schieppeti, 1989). These muscle fibers are larger and are therefore, capable of generating more force than type I fibers (Sale, 1987). During the application of force in an eccentric contraction, contractile elements are assisted by connective tissue and elastic recoil properties of muscle in producing the greater muscle forces (Bigland & Lippold, 1954; Zernicke & Loitz, 1992).

The significance of eccentric loading has been investigated comparing concentric-only training with concentric-eccentric combined training utilizing training loads of 6-12 RM (Coté, Simoneau & Legassé, 1988; Dudley, Tesch, Miller & Buchanan, 1991; Tesch & Colliander, 1991; Hather, Tesch, Buchanan & Dudley, 1991; O'Hagan, Sale, MacDougall & Garner, 1994). Conclusions shared by the above studies were that eccentric contractions were essential for maximizing muscle size and strength. When performed independently at a load greater than concentric maximum (1RM), eccentric contractions proved comparable (Rutherford & Jones, 1987, Johnson, Adamzyk, Tonnoe & Stromme, 1976) or more beneficial (Komi & Buskirk, 1972) than concentric-only training for improving strength. Komi & Buskirk compared maximal isokinetic eccentric training of the forearm flexors with maximal concentric training of the forearm flexors. Their results demonstrated that eccentric training resulted in greater increases in concentric, eccentric and isometric force production as well as hypertrophy, with significant differences existing in eccentric force production and hypertrophy.

Johnson et al. (1976), utilizing a within subject design, attempted to optimize eccentric loading by comparing a 120% 1RM load for eccentric training with a 80% 1RM load for concentric training. Subjects performed both modes of training simultaneously on opposite limbs. Eccentric training displayed greater strength gains but the differences were not significant. Results from this investigation are difficult to interpret as (a) the eccentric group performed 10% less work per set than the concentric group and (b) differences may be masked because unilateral training of both modes may produce a "cross-over" training effect. Using a similar within subject design, Jones and Rutherford (1987), found comparable responses in isometric force and hypertrophy following eccentric-independent and concentric independent training. Eccentric training intensity was set at 145% concentric 1RM which may surpass the optimal training limit thus interfering with the strength gains of eccentric training group.

When compared at equal power levels (Mayhew, Rothstein, Finucane & Lamb, 1995) concentric training elicited greater hypertrophy and isometric strength gains than eccentric training. Both modes of training were performed at 90% concentric 1RM. As the greatest capacity to generate tension occurs during an eccentric contraction (Komi & Buskirk, 1972), 90% concentric 1RM may have been less than optimal to induce strength and hypertrophic adaptations in the eccentric training group. Conversely, Hortobagyi et al (1996) observed that submaximal eccentric training was more beneficial than maximal concentric training in improving isometric force.

In a recent study, eccentric training at a load greater than concentric 1RM produced strength improvements similar to that of concentric combined with eccentric training (Ben-Sira, Ayalon & Tavi, 1996). Results from the above studies are difficult to interpret because of a) use of untrained subjects, b) unequal training volume between training groups, c) training loads were not optimal and d) mode of training was different from testing. Using elite weight lifters and trained subjects, Hakkinen & Komi (1981) concluded that a combination of concentric and eccentric training, with the eccentric load exceeding concentric maximum, is more effective than the independent use of either contraction for the elicitation of strength gains.

CONCLUSION

During concentric coupled to eccentric training the concentric load is a limiting factor since eccentric strength is greater than concentric strength. As a result, the load during the eccentric contractions may be ineffective in contributing to the strength stimulus. If load applied to the musculature is the most important stimulus for increasing strength, adjustment of the eccentric load so that it is greater than the concentric load may result in a more effective stimulus (Ben-Sira, Ayalon & Tavi, 1995). Because evidence suggests training loads must be significantly high to induce strength gains in trained individuals, adjustment of the loads during eccentric contractions may further improve strength in these subjects. Reverse recruitment during eccentric contractions, preferentially recruiting type II muscle fibers (Nardone, Romano & Schieppetti, 1989) may stimulate further hypertrophic and strength gains in trained subjects as fast twitch muscle fibers are more responsive to hypertrophic adaptation (Hakkinen, Alen & Komi, 1985; Komi, 1986; MacDougall, 1992). Greater muscle "damage" of the type II muscle fibers, associated with eccentric contractions (Cote, Simoneau, Legasse, et al., 1988),may stimulate protein synthesis as a result of a regeneration and repair process (MacDougall, 1985; Stone 1992). Strength gains, in trained athletes, as a consequence of high intensity eccentric training may also occur through neural activation adaptations as demonstrated by an elevated EMG (Komi & Buskirk, 1972; Gohner, 1994). Exposure to high loads, that are capable with eccentric training, may desensitize the golgi tendon organ (Wilson, 1995). The golgi tendon organ relays inhibitory feedback in response to high levels of tension within the muscle. Responsiveness to training seems to be a function of connective and elastic tissue that are utilized during eccentric contractions (Zernicke

& Loitz, 1992). Adaptations assumed by connective tissue and elastic components may alter the transmission of forces generated by contracting muscles resulting in a change in the biomechanics of the muscle-bone lever system (Gohner, 1994).

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APPENDIX B

Informed Consent

Comparing different resistance training intensities on strength and dynamic performance

The purpose of this study is to examine the strength changes produced by two separate resistance training protocols. Furthermore the two protocols will be compared to identify if the strength changes of these programs are significantly different.

Training Procedures

The total duration of the training period will be nine weeks. Subjects will be randomly assigned to either of two groups. The both groups will perform resistance training that incorporates a concentric phase coupled to eccentric phase. The control group will train at an intensity that is submaximal in nature. The intensity of the concentric and eccentric phases of the experimental group will differ. The concentric component will be submaximal while the eccentric component will be supramaximal. Intensity will be established relative to concentric strength. Over the duration of the study both groups will train two to three times a week. Both groups will perform the same exercises.

Data Collection

Data collection will occur prior to and upon completion of the nine weeks of resistance training. Concentric and eccentric strength along with dynamic performance will be measured using free weights. Concentric strength will be measured as the maximal load a muscle can overcome during one voluntary contraction. Eccentric strength, evaluated at a supramaximal intensity, will represent the number of repetitions a muscle can perform while controlling the rate of lengthening. Muscle cross-sectional area data will be collected using magnetic resonance imaging (MRI). The MRI procedure causes no pain or discomfort for the subject and will be conducted by highly trained lab technicians.

Informed Consent for the research project:

Effects of training with different eccentric loads on strength.

I acknowledge the purpose of this study along with research procedures outlined on the attached letter of recruitment have been explained to my satisfaction. I understand my participation in this study will involve nine weeks of resistance training. I aware that over the nine weeks of resistance training I will be expected commit approximately 1.5 hours per week. I am aware that muscular strength will be determined as described by the procedures on the attached form. I understand that muscle cross-sectional area will be measured using magnetic resonance imaging at the MRI lab at the Victoria General Hospital. I am aware that due to the nature of the resistance training I may experience some temporary discomfort due to delayed onset of muscle soreness. I am also aware that as training proceeds the discomfort due to training will subside. I understand that my participation is completely voluntary and I can withdraw from the study at any time without explanation and without penalty. Upon withdrawal, I can request that my data be destroyed. I have been guaranteed anonymity and I understand that all data collected will remain confidential and that the data will ultimately be destroyed by a paper shredder. I understand the data are accessible by the principal investigator, co-investigators along with the research supervisor. I am aware that at the completion of this investigation that I may obtain my own results from the principal investigator.

NAME:______________________________ PHONE:_______________

SIGNATURE:________________________

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Title of Thesis:

Strength, CSA and specific tension changes in trained individuals in response to resistance training programs that are different in eccentric load

Author [redacted]

Jason Peter Brndenburg
October 1, 1997