

## Research article

# IS ENHANCED-ECCENTRIC RESISTANCE TRAINING SUPERIOR TO TRADITIONAL TRAINING FOR INCREASING ELBOW FLEXOR STRENGTH?

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### ABSTRACT

Protocols for strengthening muscle are important for fitness, rehabilitation, and the prevention of myotendinous injuries. In trained individuals, the optimal method of increasing strength remains unclear. The purpose of this study was to compare the effects of a traditional method of strengthening with a method that allowed for enhanced-eccentric training, on changes in elbow flexor strength in trained subjects. Thirty-nine (8 male, 31 female) trained subjects with normal elbow function participated in this study. Subjects were rank-ordered according to isometric force production and randomly assigned to one of three training groups: control (CONT), traditional concentric/eccentric (TRAD), and concentric/enhanced-eccentric (NEG). The training groups completed 24 training sessions. An evaluator blinded to training group performed all testing. Mixed model ANOVA techniques were used to determine if differences existed in concentric one repetition maximum strength, and isometric force production among groups. Changes in peak and average isokinetic force production were also compared. Type 1 error was maintained at 5%. While both groups improved concentric one repetition maximum (NEG = 15.5%, TRAD = 13.8%) neither training group statistically differed from changes demonstrated by the CONT group. Nor did either training group show significant improvements in isometric or isokinetic force production over the CONT group. These results do not support the superiority of enhanced-eccentric training for increasing force production in trained subjects.

**KEY WORDS:** concentric, specificity, negative training, one-repetition maximum, isokinetic

### INTRODUCTION

Eccentric muscle actions are common during many daily activities such as walking and running. The primary role of eccentric muscle actions in these activities has been described as one of deceleration and energy absorption (Stauber, 1989). Because of the high forces associated with eccentric muscle actions, muscle strains and myotendinous injury are more commonly associated with activities involving eccentric loading than activities involving only concentric loading (Glick, 1980; Garrett Jr., 1990).

Muscle strengthening is critically important for injury prevention, rehabilitation, and

performance enhancement (Johnson et al., 1972; Stauber, 1989). Training regimens that do not emphasize eccentric actions may not prepare individuals for the eccentric loading that occurs during many athletic and daily activities. Enzymatic markers of muscle damage following exercise are commonly found after performance of eccentric exercise (Ploutz-Snyder et al., 1998). In addition, training studies have demonstrated that *morphological changes* in muscle have been greatest in those studies combining both concentric and eccentric muscle actions (Doss and Karpovich, 1965; Johnson et al., 1972; Colliander and Tesch, 1990; O'Hagan et al., 1995). It has been postulated

that connective tissue changes associated with eccentric muscle actions contribute to muscular hypertrophy, (McDougall et al., 1984) which in turn may offer some resistance to injury (Stauber, 1989).

When using traditional isotonic strengthening programs, the maximal amount of weight is limited to that which can be lifted during the concentric phase of the intended joint motion (i.e. elbow flexion). This weight represents a different training load when comparing the maximal amount of tension developed concentrically versus eccentrically. The development of an isotonic-eccentric device called the Negator™ (Myonics Corporation, Metairie, LA, USA) offers a solution to this limitation by enabling enhancement during the eccentric phase of the exercise maneuver. By enhancing the eccentric load, the muscle can be loaded maximally during *both* the concentric and eccentric phases of the lift.

Previous work with the Negator™ demonstrated that enhanced-eccentric training involving the hamstring musculature provided superior increases in concentric one repetition maximum (C1RM) lift strength over a conventional isotonic training program (Kaminski et al., 1998). The purpose of this study was to determine the effects of enhanced-eccentric training on elbow flexor force production in a group of trained subjects. We hypothesized that the concentric/eccentric-enhanced training group would demonstrate greater gains in non-specific tests (isometric and isokinetic) of force production than concentric/eccentric isotonic training of the elbow flexors.

## METHODS

### *Subjects*

A university's Institutional Review Board approved the methods and procedures used in this investigation. Documented informed consent for testing and training was obtained from the 39 volunteers (8 males, 31 females). Initial power calculations derived from isometric pilot data indicated that 12 subjects per group were required to find differences between the treatment groups ( $\beta=0.2$ ,  $\alpha=0.05$ ). Due to the vigorous nature of the eccentric training, subjects were included only if they had weight-trained their upper extremities twice a week for at least three months prior to beginning the study. Current musculoskeletal pathology affecting the upper extremity, any medical limitations toward heavy resistance exercise, or a history of anabolic steroid use resulted in exclusion from the study. Subject data are summarized in Table 1.

**Table 1.** Anthropometric data of subjects within each group (n =13). Data are mean (SEM).

	NEG	TRAD	CONT
Age (years)	23.6 (5.2)	22.3 (.8)	20.6 (1.0)
Height (cm)	167.0 (9.4)	167.0 (9.0)	168.7 (6.7)
Weight (kg)	62.4 (14.1)	64.8 (6.7)	72.4 (12.3)
SI	1.1 (.3)	1.0 (.3)	1.1 (.3)

NEG = concentric/enhanced-eccentric, TRAD = concentric/eccentric, CONT = control group, SI = Strength Index ( $N \cdot kg^{-1}$ ).

### *Instrumentation*

The Negator™ enhanced eccentric isotonic device allows for independent manipulation of eccentric weight without changing the existing variable resistance machinery. We attached the Negator™ to a Cybex (Cybex Division, Lumex, Inc., Ronkonkoma, NY) arm curl apparatus. The Negator™ device has been described in detail elsewhere (Kaminski et al., 1998). It consists of a separate mechanically controlled weight stack (2.3kg increments) that attaches to a standard variable resistance device. The device provides assistance during the concentric phase of the lift. As the weight-stack passes a calibrated location at the end of the concentric phase of the motion, the Negator™ deactivates, removing the assistance, thereby increasing the weight to be lowered (eccentric phase). Thus, if a subject in the NEG group had a C1RM of 50 kilograms, the training protocol would call for the concentric phase starting weight to be 66% of 50 kg, and the eccentric phase starting weight to be 100% of 50 kg. For example, the Cybex arm curl machine would be set at 50 kg with the Negator™ activated and set to provide 16 kg of assistance, making the concentric weight 34 kg. At the completion of the concentric phase, the Negator™ would deactivate, removing the assistance, and the subject would then lower the entire 50 kg during the eccentric phase.

### *Procedures*

A Kin Com 125 AP (Chattanooga Group, Inc., Chattanooga, TN) isokinetic dynamometer was calibrated before each of the testing sessions and used to measure the isometric and isokinetic force production of the elbow flexors. During testing, the subject sat upright on the dynamometer chair in the manufacturer's recommended position for elbow flexion testing. Two straps crossed the subject's chest to limit trunk motion. A handle, attached to the actuator for the subject to grip, maintained the forearm in supination. The subject was encouraged to give a maximal effort during all testing and received both visual and verbal feedback to maximize effort (McNair et al., 1996). The order of

testing mode (isometric vs. isokinetic) was randomized by a coin toss prior to data collection. The same evaluator (MDB) tested all subjects and remained blinded to group status during the entire study duration. All subjects completed a familiarization session prior to the actual test session.

Peak isometric force was measured at five angles of elbow flexion (10°, 25°, 60°, 85°, and 110°) on the right upper extremity. The order of testing was counter-balanced using a Latin square. Subjects were instructed to build-up tension against the dynamometer lever arm, while slowly attempting to flex the right arm ("isometric hold"). They were then instructed to hold this peak isometric tension for two seconds. Peak isometric force was measured separately three times at each joint angle. The average of the three trials at each angle was used for data analysis. Twenty seconds of rest was provided between each trial at the same angle and three minutes of rest between each testing angle (Kaminski and Hartsell, 2002, Clarke, 1971). A subgroup of six subjects returned within five days to repeat testing and allowed their data to be used in the analysis of test-retest measurement reliability.

Isokinetic testing was performed at 40°·s<sup>-1</sup>. This testing velocity was derived based on the amount of time it took our subjects to perform the isotonic arm curl manoeuvre. A warm-up of 10 submaximal repetitions was performed, followed by a 3-minute rest period. Each subject performed three maximal concentric and eccentric elbow flexion repetitions using the "overlay" feature on the Kin Com dynamometer. This resulted in each action being completed in a separate and isolated sequence. One minute of rest was allowed between each muscle action. All subjects verbally indicated that they had given a maximal effort during the testing. This we confirmed by using a modified perceived exertion scale (Borg, 1978).

Additionally, each subjects' C1RM was determined by having them perform sequential one-repetition bilateral arm curls with increasing resistance using the Cybex arm curl machine. Two minutes of rest were provided before a new weight was introduced. The weight was increased until the subject was unwilling or unable to lift the heavier load. This final weight was considered the C1RM and subsequently used to determine the initial training weight.

### *Resistance Training*

Once the subjects had completed their initial strength tests, a strength index was created to determine treatment group assignments. Isometric force was averaged across all joint angles and expressed relative to body weight (N·kg<sup>-1</sup>). Subjects

were then rank-ordered based on this strength index value. Following this, the group assignment for the first subject was randomly drawn from the first row of a Latin square. The subjects were then placed in either the concentric-enhanced eccentric group (NEG), the concentric-eccentric group (TRAD), or a control group (CONT) based on this random assignment strategy. Those subjects assigned to the control group were instructed to continue with habitual activity without modification to their training regimen.

All training was done using the Cybex arm curl machine. The seat height of the arm curl machine was adjusted so that the subject's right arm was maintained in 70° of shoulder joint flexion when resting on the elbow pad. Subjects performed the arm curl maneuver with both arms using a 'two count' (two seconds up for the concentric phase and two seconds down for the eccentric phase) cadence. This particular cadence was chosen since it represented the manner in which student-athletes at our institution are traditionally instructed to move during arm curl resistance training utilizing free-weights.

**Table 2.** Training protocol.

Week	Session/wk	Sets	Rep/set	RI
1 – 4	2	3	10	1 min
5 – 8	2	3	8	2 min
9 – 12	2	3	6	3 min

Rep= repetitions, RI= rest interval.

Subjects in the TRAD group began training at 60% of their C1RM. If subjects could perform 100% of all the required repetitions at the prescribed resistance, training weight was increased 5% at the next training session. As long as the subject could perform a minimum of 66% of the prescribed repetitions, the new weight was maintained as the training resistance for subsequent sessions, otherwise the weight was decreased by 5%. Once the subject was able to perform 100% of all the required repetitions at the lower weight, the resistance was again increased as previously described. The NEG group used the same training protocols and starting concentric weight (60% C1RM) as the traditional group. However, the eccentric weight was set at 100% of the C1RM. The subjects trained twice a week for twelve weeks. Table 2 outlines the training protocol used. The training group subjects were constantly reminded to comply with the training protocol via telephone calls and e-mails. The post-test strength assessment was conducted in a similar manner to the pre-testing and commenced within a week after completing the final training session.

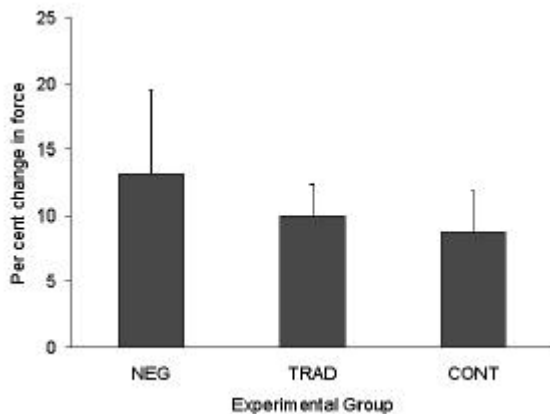
### Statistical Analysis

A one-way analysis of variance (ANOVA) was used to compare each anthropometric variable (age, height, weight, strength index) among groups before training. The test-retest reliability of the isometric strength index measurements of 6 subjects was determined using an intraclass correlation coefficient ( $ICC_{2,1}$ ).

Changes in CIRM were identified using a mixed model (between subject factor = group, within subject factor = pre and post-test) ANOVA with repeated measures on the dependent variable.

The dependent variable for isometric testing was the percent change in the mean peak isometric force at each testing angle (10°, 25°, 60°, 85°, and 110°). Training effects were determined using a mixed model ANOVA (between = group, within = angle) with post-hoc one-way ANOVA contrasts and follow-up pairwise comparisons using Dunn-Bonferroni corrections.

Given the close association between the isokinetic dependent variables (peak concentric and eccentric force, and average concentric and eccentric force), a multivariate analysis of variance (MANOVA) was conducted with one-way post-hoc contrasts performed, followed by pairwise comparisons using Dunn-Bonferroni corrections. The family-wise type 1 error was set at 5%.



**Figure 1.** Percent change (pre- to post) in concentric one repetition maximum. Bars represent mean (SEM). NEG = concentric/enhanced-eccentric. TRAD = concentric/eccentric. CONT = control.

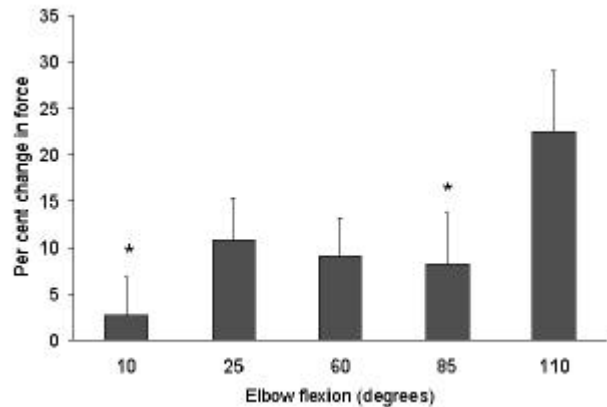
## RESULTS

Thirty-five of the initial thirty-nine subjects completed the study (11% attrition rate). Time inconvenience was given as the primary reason for dropping out (one subject from each of the training groups and two from the control group). There were no differences noted among the groups for any of the anthropometric data assessed. Test-retest reliability

of the isometric strength index measurements was found to be high ( $ICC=0.94$ ).

### CIRM

Training load increased an average of 27% over the course of the twelve-week training period. After 24 training sessions, the NEG group increased elbow flexion CIRM by 15.5% while the TRAD group increased by 13.8%. Despite these changes, no significant interactions were noted between the group and time factors ( $F_{2,76}=1.2$ ,  $P=0.44$ ) for CIRM. Additionally, there were no group main effects ( $F_{2,37}=0.51$ ,  $P=0.48$ ). There was a trend for NEG group to have increased CIRM greater than the CONT group, however this difference did not reach significance (Figure 1). The same was not true between NEG and TRAD training groups. The twelve weeks of training did result in a significant increase in CIRM ( $F_{1,36}=20.0$ ,  $P<0.005$ ) in both strength training groups.



**Figure 2.** Mean (SEM) percent change in isometric force collapsed across angle. \*  $p<0.05$  compared to 110° angle.

### Isometric Force

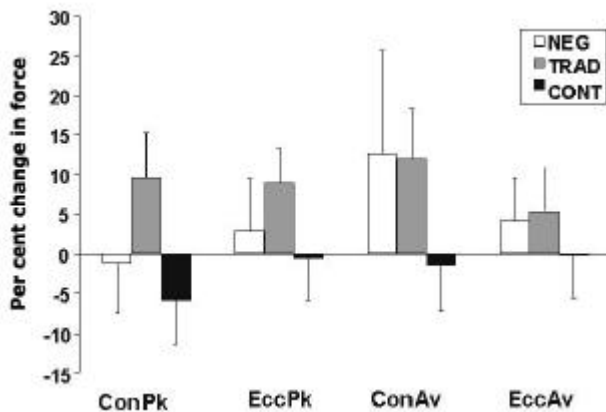
No interaction was noted among the groups at any of the isometric angles tested ( $F_{7,28}=1.48$ ,  $P=0.17$ ). Interestingly, one subject in the NEG group improved at the 110° isometric test angle by 150% resulting in the large amount of variability within the NEG group (the average difference in isometric force produced at 110° for the group was  $36.5 \pm 23.1\%$ ). The data from this subject at this angle did meet the requirements for rejection as an outlier; however, none of the remainder of the data from this subject were categorized as being outlier data. Thus, this subject was included in the overall analysis.

After 12 weeks of isotonic strength training, there was no group main effect ( $F_{2,32}=0.15$ ,  $p=0.86$ ) indicating that the training groups were not different statistically from the control group. However, there was an angle main effect for ( $F_{4,108}=2.657$ ,  $p=0.037$ ). The change in force at 110° was greater than

than that at 10° ( $F_{1,29} = 4.59$ ,  $P=0.041$ ) and 85° ( $F_{1,29}=5.56$ ,  $P=0.025$ ) (Figure 2).

### Isokinetic Force

The MANOVA results (Wilk's Lambda=0.511,  $F_{8,38}=1.892$ ,  $P=0.09$ ) indicated that none of the dependent variables within this analysis showed changes that were statistically significant. Large percentage changes occurred within the NEG and TRAD groups when considering the average concentric force produced throughout the range of elbow flexion. However, high within group variability resulted in few of these changes being different from zero (Figure 3).



**Figure 3.** Mean (SEM) percent change in isokinetic force (Nm). ConPk = concentric peak force, EccPk = eccentric peak force, ConAv = average concentric force, EccAv = eccentric average force.

## DISCUSSION

Our original purpose had been to determine whether a training regimen that included enhanced-eccentric muscle actions would be superior to a traditionally used method of training, when trained individuals attempt to increase their elbow flexor strength. The results of this study suggest that although dynamic training load increased by approximately 27% for both training groups; the CIRM analysis did not support the superiority of enhanced-eccentric training for improving isotonic elbow flexor strength in a group of trained subjects. This is in direct contrast to a previous study using enhanced-eccentric muscle actions involving the hamstring muscles (Kaminski et al., 1998). In that study, it was reported that the enhanced-eccentric group improved CIRM by 29% while the traditional group improved 19%. Those changes occurred after only 6 weeks of training. Based on this, the possibility exists that a group difference (between the eccentric-enhanced training and the traditional training) may have occurred in our current study at 6 weeks; yet this difference disappeared over the course of the

additional 6 weeks of training.

In adhering to this logic it suggests that the time course to neural adaptation is more rapid when using enhanced-eccentric muscle actions. Previous studies report increased neural adaptation from eccentric training (Housh et al., 1996; Aagaard et al., 2000; Uh et al., 2000) and that there appears to be differing activation strategies for concentric and eccentric muscle actions (Bishop et al., 2000). It is possible that a different time course to adaptation may also exist for each muscle action and the NEG group may have shown a more rapid increase in CIRM than TRAD. In the current study, manipulation of the concentric and eccentric weights for the NEG group occurred separately; that is, subjects would often improve in only one phase (concentric OR eccentric) for several sessions, plateau and then begin to improve in the other phase.

Changes in isometric strength were not different between training groups, nor were the training groups significantly different from the control. Furthermore, and perhaps most surprising, was that isokinetic force production was not affected by 12 weeks of strength training. This is in agreement with previous studies which have used isometric testing to compare groups that have trained with concentric OR eccentric muscle actions only (Komi and Buskirk, 1972; Jones and Rutherford, 1987) but in contrast to Seger et al. (Seger et al., 1998) who noted increases in isometric strength in both concentrically and eccentrically trained groups.

Winters et al. (Winters and Kleweno, 1993) examined the effect of shoulder position on torque generation of the elbow flexor muscles. They found significant strength gains in the training position and little or no gains in an unfamiliar position. In the present study, the subjects trained their elbow flexors with the humerus supported at 70° of shoulder flexion bilaterally, while gripping the Cybex arm curl handle, whereas they were tested using a unilateral forearm flexion protocol with the arm at their side. This suggests that this subtle variation in testing versus training arm position may have accounted for the lack of difference post training in either of the groups. The presence of a two-joint muscle allows for creation of a non-specific angle of testing to be used. The position of the arm in relation to the thorax alters the length of the long head of biceps and introduces the factor of muscle length specificity. Furthermore, the humerus was not supported during testing while it was during training. Thus during the testing the subject had to dynamically stabilize their trunk and glenohumeral-scapulothoracic joint complex possibly resulting in a decreased ability of the prime movers (biceps brachii and brachialis) to generate elbow flexion torque.

Research into the area of specificity has

considered angle, velocity, and mode specificity (Morrissey et al., 1996). Many researchers have therefore incorporated some elements of mode, angle, or velocity specificity into their testing protocols. This may explain the small, but significant carryover seen in their results. By considering posture and two-joint specificity in the development of the non-specific test, this study may have eliminated the carryover seen in other studies. Consideration should also be given to the fact that a review of blinded versus non-blinded trials (Chalmers et al., 1983) demonstrated that when a study is blinded such as the present study, the null hypothesis is likely to prevail.

Although changes were noted in mean values of C1RM, and isokinetic variables for the training groups, the within group variability was large. Our subject pool consisted of a group of strength-trained individuals who may not have made as much change in strength as one might expect in a group of untrained subjects (Higbie et al., 1996; Seger et al., 1998). With this in mind, we had expected that any changes made in trained subjects would be small, however, our *a priori* power analysis had indicated that, at least for isometric testing, 12 subjects were needed for our effect size to produce statistically significant results. It is apparent from our results that this was not the case.

Weaknesses in this study's design include failure to evaluate the reliability of the one-repetition maximum (1 RM) protocol. A literature search on commonly used 1RM protocols produced no studies on reliability. Another potential flaw in methodology is the possibility that fatigue occurred during the testing battery. Subjects in this study performed a series of maximal efforts, isometrically and isokinetically. We allowed subjects to have three minutes of rest between isokinetic actions, and three minutes rest in between each of the angles tested isometrically. At each of the angles tested, however, we allowed twenty seconds of rest. It is possible that this was not sufficient rest to eliminate muscular fatigue during isometric testing. If subjects were experiencing muscular fatigue the results of the test protocol may not reflect the maximal muscular performance of the subject.

## CONCLUSION

In contrast to previous work using enhanced-eccentric resistance training, we did not find that this type of training provided superior strength gains over traditional training in our group of trained subjects. Although the small strength gains we elicited might have a clinically meaningful result for the trained subject (i.e. a five pound increase in

personal best lift) there were no statistically significant differences between the training groups.

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