Can Antagonist Resisted Training
Improve the Ability to Cocontract?

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# Table of Contents

Acknowledgements........................................................................................................ 3

Abstract ....................................................................................................................... 4

Introduction .................................................................................................................. 5

Review of Literature .................................................................................................... 7

Methods

Subjects ....................................................................................................................... 10

Apparatus, Testing Position, and Testing Schedule ................................................. 10

Training ....................................................................................................................... 13

Normalization ............................................................................................................. 13

Statistical Analysis ................................................................................................... 15

Results ........................................................................................................................ 16

Discussion .................................................................................................................. 23

Conclusion .................................................................................................................. 30

References .................................................................................................................. 31

Appendices

Appendix A – R.E.B. Approval .................................................................................. 35

Appendix B – Invitation to Participate Letter and Consent Forms ......................... 42

Appendix C – Training Regimen ............................................................................... 47
Acknowledgements
Abstract

CAN ANTAGONISTIC RESISTANCE TRAINING IMPROVE THE ABILITY TO COCONTRACT?

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PURPOSE: The aim was to determine if antagonist resisted training could improve an individual’s ability to cocontract antagonistic muscles in a sample of 20 female university students. METHODS: EMG analysis was used to determine the muscle activity of the triceps brachii during maximal isometric cocontractions of the elbow flexors and extensors. Data was recorded before and after a 6 week training program during which the subject’s underwent left-arm exclusive training, with the right arm serving as the control. Training focused on increasing biceps strength while using triceps muscle force as the source of resistance. Various dynamic cocontraction exercises were used during training. Change scores were determined for each arm by subtracting pre-test EMG measurements from post-test values. An independent samples t-test for unequal variances was applied to compare the change scores. RESULTS: The EMG activity of the antagonist of the trained arm (mean change = .08, sd = .13) showed significant improvement relative to the untrained arm (mean change = -.004, sd = .05), t(24) = 2.71, p = .024. CONCLUSIONS: Antagonistic resistance training increases an individual’s ability to cocontract, and could be an effective and beneficial form of resistance training.
Introduction

The purpose of the present study was to determine whether or not resistance training can enable an individual to increase the amount of resistive force produced by an antagonistic muscle in a maximal voluntary isometric contraction (MVIC). Although it may seem contradictory to contract opposing muscle groups simultaneously, this phenomena of cocontraction is regularly observed within normal muscle functioning. Coactivation of agonist-antagonist muscle pairs has been demonstrated to be important in joint stability (Barratta et al., 1988; Gabriel, Basford, & An, 1997; De Luca & Mambrito, 1987), rapid movements (Milner, 2002), and learning new motor tasks (Calder & Gabriel, 2006). This information suggests the functional importance of being able to cocontract muscles. Much research has investigated the mechanism of muscle activation and contraction. Very simplistically, a signal sent from the central nervous system is propagated along efferent nerves towards a muscle. Once the signal reaches the muscle, a series of events are triggered in the muscle whereby calcium ions are released allowing for contraction of the muscle. It seem plausible to expand this mechanism to describe cocontraction, simply having this set of events occur simultaneously in agonist and antagonist. However, simultaneous excitation of both flexor and extensor would be ineffective as both muscle groups would be excited and inhibited at the same time due to reciprocal inhibition. Thus, it becomes evident that the mechanism of cocontraction is more complex. De Luca and Mambrito (1987) suggest that there is a common drive mechanism controlling the musculature and, depending on the intended action, there is a different form of control. In understanding this control, together with knowing that resistance training has been shown to result in either physiological and/or neurological adaptations (Sale, MacDougall, Always, & Sutton, 1987; Sale, 1988), the idea of a common drive may possibly be used to develop resistance training programs that elicit simultaneous
adaptations in both agonist and antagonist. Monitoring changes in electrical activity within the muscles by means of electromyography can reveal whether or not neurological adaptation has occurred (Sale, 1988). Interpreting the electromyographic (EMG) activity allows one to make valid predictions on the maximal contractile force that is being produced by the muscle. As well, any neurological adaptations that may occur in response to the stresses of training will result in an increased ability to generate force within the muscle, as represented by increases in EMG activity (Moritani & de Vries, 1979). Artificially inducing a contraction in an antagonistic muscle has been shown as an effective means of producing a resistive force to the agonist, as well as improving the maximal force produced by the agonist and antagonist (Yanagi et al., 2003). The current investigation will attempt to determine if it is possible to increase the level of muscle force generated by the antagonist during cocontraction.
Literature Review

Sherrington’s work on the neuromuscular system and reciprocal innervation (Sherrington, 1909) set the stage for numerous investigations into the mechanism behind the control of antagonistic muscles. De Luca and Mambrto (1987), for example, suggest that antagonists may be controlled by a common drive. Results from their study showed that the motor units (MU) of the agonist and antagonist fired in unison. This suggests that there is some central control over the firing rate which acts uniformly on the entire motoneuron pool innervating agonist and antagonist muscles, rather than on individual MU. De Luca and Mambrto (1987) also propose a three-channel model for the control of agonist and antagonistic MU. This model states that separate “flex” and “extend” commands exist to control reciprocal actions, while the third command, coactivation, controls the pure cocontraction of the antagonistic muscles. These two concepts of common drive and the three-channel model are observed within muscle activity. During flexion, the flexor MU would be stimulated through the action of the common drive on the flexor motoneuron pool. This would cause excitation in the agonist while inhibiting the antagonist, via reciprocal innervation. The opposite would be true for extension. Coactivation, however, requires a different method of control. If the flexion and extension commands were simultaneous, then the excitation and inhibition would cancel each other out (De Luca & Mambrto, 1987). The coactivation command would therefore act on a coactivation motoneuron pool which would have an excitatory effect on both agonist and antagonist. This notion of different controls for the different aspects of agonist/antagonist contraction states is supported by electrophysiological evidence provided by Frysinger et al. (1984), as well as research conducted by Nielsen and Kagamihara (1994). The thoughtful implementation of these principles into a strength training program may be able to elicit a neural adaptive response in both agonist and
antagonist. In fact, there is research suggesting the level of coactivation in antagonistic muscles is trainable through some form of resistive training (Colson, Pousson, Martin, & Van Hoecko, 1999; Gabriel, Basford, & An, 1997; Carolan & Cafarelli, 1992).

Resistance training typically results in physiological adaptation (Sale, 1988; Farina, Merletti, & Enoka, 2004), as well as rapid neuromuscular adaptation (Pucci, Griffin & Carafelli, 2006; Sale, 1988; Chilibeck, Calder, Sale, & Webber, 1998). These neuromuscular adaptations include, among others, changes in neuronal firing rate and motor unit recruitment. It was stated by Pucci et al. (2006) that the resulting neuromuscular adaptation caused by dynamic resistance training is an increase in the maximal motor unit firing rate. Sale (1988) proposed that resistance training may lead to changes within the nervous system resulting in an increased ability to activate agonistic muscles. Although resistance training is primarily focused on inducing adaptations in agonistic muscles, several researchers have examined the adaptations in the antagonist muscle in response to training. While studies focusing on isometric training have seen decreased neural activity of the antagonist (Carolan & Cafarelli, 1992), studies using eccentric training saw no significance changes from pre to post training (Colson et al., 1999; Hortobágyi, Hill, Houmard, Fraser, Lambert, & Israel, 1996).

Electromyographic analysis of the muscular electrical activity can provide an indication as to whether neural adaptation has occurred in trained muscles (Sale, 1988). Surface electromyography (sEMG) amplitude is directly related to the neural activity of the monitored muscles (Farina, Merletti, & Enoka, 2004). Gabriel (2000), and Gabriel and Boucher (1998), suggest that increases in both signal frequency and spike content of sEMG are indicative of muscle activity changes due to training. Similarly, it has been shown that increases in sEMG amplitude are a result of increased motor unit recruitment and/or firing rate (Farina et al., 2004).
Differentiation between the two has been determined impossible due to several limitations as discussed by Farina et al. (2004). Moritani and de Vries (1979) demonstrated that initial strength gains, as a result of strength training, are due to neural adaptations. These strength gains will be visible as an increase in the maximal force production of the muscle, which in turn can be determined through interpretation of EMG activity in the muscle.

Recently, Yanagi et al. (2003) implemented a novel resistance training technique utilizing neuromuscular electrical stimulation (NMES). The training involved the concentric contraction of an agonist muscle against the resistance of an artificially induced contraction in the antagonist. The results of this study suggested that this strength training technique was effective at producing physiological adaptations and strength gains. As sEMG was not incorporated into this study, there was no way of determining if any neurological adaptation took place in either agonist or antagonist. Though this training technique has obvious advantages in rehabilitation settings (Yanagai et al., 2003), if a maximal voluntary contraction (MVC) of an antagonist muscle could provide adequate resistance for the agonist, this form of training would be accessible to a much larger population.

Therefore, the purpose of this study was to determine if antagonist resisted training can improve an individual’s ability to provide resistance with their antagonist muscles. Specifically, this investigation looked at whether dynamically contracting an agonist muscle against the maximal voluntary contraction of its opposing antagonist can improve the antagonist’s ability to produce a resistive force. Over a 6 week period, the biceps brachii (BB) was dynamically contracted against the maximal voluntary contraction of the triceps brachii (TB). It was expected that through training, the subjects would be able to increase the resistance provided by the TB, and in turn develop more neural activity in both BB and TB.
Methods

Subjects

For the current investigation, 23 right-handed university aged females were recruited through word of mouth. Females were emphasized due to the trial and day error variances of men, which have been demonstrated to be between two and four times higher than in women (Kroll, 1970). The subjects all reported having little or no weight training experience, and had not trained within the previous six months. The exercises, risks, testing protocols, and the time required to complete all phases of the study were explained to each of the participants before they read and signed the informed consent documentation found in the Invitation to Participate letter (Appendix A).

Apparatus, Testing Position, and Testing Schedule

EMG data were obtained from two Delsys DE-2.3 single differential sEMG electrodes. One electrode was placed on the belly of the biceps brachii (BB) at approximately the midpoint between the glenohumeral joint and the antecubital space (Fig. 1). The second electrode was placed over the lateral head of the triceps brachii (TB; Fig. 1). This placement was selected on the fact that Lehman (2005) found the lateral head of the TB to show high levels of activation with the forearm in a pronated position, as it was in the triceps testing protocol. The skin in the area of electrode placement was cleaned and lightly abraded with rubbing alcohol and cotton pads to reduce impedance at the skin-electrode interface. A reference electrode was placed directly over the lateral malleolus of the left ankle. Indelible ink was used to mark the location and position of the electrodes. This assisted in keeping the electrode placement consistent throughout the duration of the study. Data were collected with a common mode rejection ratio
(CMRR) of 92 dB at a sampling rate of 2048 Hz. The pre-amplified signal was band-pass filtered with a frequency range of 20 to 450 Hz.

Fig 1. Electrode placements on the biceps and triceps brachii

Despite training the left arm exclusively, data was collected from both the left and right BB and TB. There were 3 different conditions under which the data was collected: biceps external resistance (BER), triceps external resistance (TER), and cocontraction (CO). Data from the trained arm (left) was compared to the data from the untrained arm (right), which served as the control measurements.

For all test conditions, the subjects stood erect with 90° elbow flexion in the sagittal plane, upper arm by their side. The opposite arm hung freely at their side. In the BER and cocontraction conditions, the palm was in a supinated position, while during TER, the palm was pronated. External resistance during bicep contractions was provided by a stirrup handle.
connected to a section of chain which was securely fastened to the floor. The section of chain was adjustable in order to maintain 90° elbow flexion for all subjects. A force transducer located serially within the chain was used to collect force data to be examined in a separate study (Rannelli et al.). The same chain setup, securely fastened to the wall in front of subjects, was used for the externally resisted tricep contractions.

Fig. 2 Testing position for the externally resisted biceps contraction (a), cocontraction (b) and the externally resisted triceps contraction (c).

Testing began with the BER condition, during which subjects were instructed to maximally contract the BB against the resistance of the chain for a duration of 5 seconds. Contraction time was controlled by a digital timer within the computer program used to record the EMG data (MyoMonitor Data Acquisition Software), with the experimenter saying “three, two, one, go.” During the contraction, verbal encouragement from the researcher was provided. Following the five seconds of contraction, the experimenter instructed the subject to relax.

Following the BER contractions, MVIC’s were performed using internal resistance. The subject’s position remained the same as described above. The subjects were instructed to isometrically cocontract the BB against the TB maximally for a 5 second duration. Again, the 5 seconds was controlled by the experimenter and verbal encouragement was provided.
After testing for the cocontraction condition was completed, TER contractions were performed. In the position described above, with palm in pronation, the subjects were instructed to maximally contract the TB against the wall mounted chain for 5 seconds. A total of two trials for each arm were collected under each condition.

Two testing sessions were performed 7 weeks apart: the first test occurring before the initial training session, and the second test immediately following the training program.

Training

The 6-week training program consisted of exclusively left-arm training exercises. The subjects were required to attend three training sessions per week for the 6 week period. Eccentric, concentric, and concentric-eccentric combination movements were the three types of exercises. The number of repetitions was varied from week to week in an attempt to manipulate the intensity. The intensity started low with a few repetitions, peaking midway through the training program with higher repetitions and the assumed learned ability to cocontract. It was assumed that over the course of the study, each subject developed the ability to cocontract the bicep and tricep, and as this task was learned, the intensity of contraction increased. The intensity then tapered off as the program concluded in an effort to increase post-test performance, as research suggests (Gibala, MacDougall, & Sale, 1994). A copy of the training regimen is included in Appendix C.

Normalization

Typical EMG analyses should involve the normalization of the EMG signal to a calibrated contraction (Lehman & McGill, 1999). Perhaps the placement of electrodes differed
slightly from pre to post testing, resulting in placement of the electrode closer to an innervation zone. Consequently, an increase in sEMG activity would be recorded, even in the absence of neurological adaptations. Normalization would allow for a more meaningful comparison of these pre and post test signals by controlling for factors such as these; factors which have an influence on the amplitude of the sEMG signal. According to Lehman & McGill (1999), one of the best methods of normalization in a healthy population is expressing the sEMG amplitude as a percentage of the maximum voluntary contraction (MVC) of the same muscle, at the same joint angle. Due to the nature of the present study, normalization of the data in this manner would potentially result in false indications. Through training, it would be expected that increased neural activity would occur (Moritani & de Vries, 1979). This increase would be present whether the contraction is an externally resisted MVIC or, for example, an internally resisted MVIC. Therefore, normalizing the sEMG signal by expressing as a percentage of MVC would show no change even if training induced neurological adaptations occurred. As the amplitude of both signals would increase, their ratio would remain constant. In light of this potential problem, the sEMG data collected in this investigation was not normalized before analysis.

However, the design of the present study did not require normalization for meaningful interpretation of the data. Due to the incorporation of the control arm data, as well as using change scores, extraneous factors having the potential to alter the sEMG amplitude were accounted for. Changes scores were determined by subtracting the sEMG amplitude values obtained during the post test session from those obtained during the pre test session. Any systematic changes to the placement of electrodes would be random at best, and would affect both trained and control arms in a similar manner. When determining the pre to post change score for each arm, the effects of electrode placement would be included in this value. With both
the control arm change score and the trained arm change score containing these extraneous factors, differences in these scores would not be significant when averaged across the subject pool. From this, it is evident that significant differences found within the data were due to neural adaptations within the muscle.

Statistical Analysis

The raw EMG data were used to calculate the root-mean-square (RMS) amplitude of sEMG activity for both biceps and triceps brachii according to the formula proposed in Basmajian and De Luca (1985). The peak RMS value taken from the middle second of data were determined for each trial, and the maximum value of these two peak values was used as the subject’s maximum RMS sEMG (RMS\text{\textsubscript{max}}) value. Data were then separated into four groupings established from the three contraction conditions; biceps external resistance (BER), triceps external resistance (TER), and two internal resistance groupings from CO, biceps internal resistance (BIR), and triceps internal resistance (TIR). For each condition, only the sEMG data from the specified muscle during the specified condition was analysed. Within each grouping, change scores were established for the trained and untrained arms.

A single-tail, unpaired t-test, assuming unequal variance, was used to test for statistically significant differences between the change scores of the trained and untrained arms in each condition. Due to the multiple comparisons done in this study, together with the correlated hypotheses, the Holm-Sidak step-down multiple comparison procedure (MCP) outlined in Ludbrook (1998) was used to adjust the comparison-wise P-values. The Holm-Sidak step-down correction was chosen as it has been demonstrated to be among the most accurate and powerful methods of controlling type I error rate when multiple comparisons are made.
Results

Twenty-three university-aged females were recruited for the study. Three subjects withdrew from the study by the fourth week, and their data were not used. The remaining twenty subjects completed a minimum of 16 training sessions, with 18 of 20 subjects attending 17 sessions over the 6 week period.

After the 6 week training period, a 92% increase in EMG activity was observed in the trained left triceps brachii muscle during TIR, while the untrained right triceps only exhibited a 6% increase (Fig. 3, Table 1). Within the BIR condition, the EMG activity of the left biceps brachii increased 39%, although the right biceps showed a large increase as well (19%) (Fig. 3, Table 1). For TER, the trained triceps showed a 43% increase in activity with the untrained triceps decreasing by 4% (Fig. 4, Table 1). Additionally, the increase in the trained bicep’s EMG activity during BER (25%) was greater than the change seen in the untrained arm (5%) (Fig. 4, Table 1).

Table 1 Percent and raw EMG changes of the trained and untrained biceps and triceps brachii muscles after 6 weeks of ART. Values are mean (SD)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Trained Arm</th>
<th>Untrained Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent Change</td>
<td>Change Score (V)</td>
</tr>
<tr>
<td>BIR</td>
<td>38.73 (60.03)</td>
<td>0.05 (0.08)</td>
</tr>
<tr>
<td>BER</td>
<td>25.46 (51.34)</td>
<td>0.06 (0.12)</td>
</tr>
<tr>
<td>TIR*</td>
<td>92.17 (121.26)</td>
<td>0.08 (0.13)</td>
</tr>
<tr>
<td>TER</td>
<td>43.36 (104.38)</td>
<td>0.10 (0.30)</td>
</tr>
</tbody>
</table>

BIR – Biceps internal resistance
BER – Biceps external resistance
TIR – Triceps internal resistance
TER – Triceps external resistance
Trained Arm = left; Untrained Arm = right
* statistical significance between trained and untrained arms
Fig. 3 Percent changes from pre to post testing sessions during internal contractions of the trained and untrained arms. Error bars represent standard deviations. Black boxes represent trained arm, grey boxes represent untrained arm.

Fig. 4 Percent change from pre to post testing sessions during external contractions of the trained and untrained arms. Error bars represent standard deviations. Black boxes represent trained arm, grey boxes represent untrained arm.
As Table 1 depicts, the standard deviations in the data were quite large. The researchers hypothesized that these large deviations are due to between-subject differences in the intensity of training. Due to the nature of ART, there are no standardized weights to base intensity on. It was assumed that each subject was able to cocontract the bicep and tricep during the dynamic movements, however, the researchers had no way of determining this. While some subjects may have been maximally cocontracting throughout the movements, other subjects could simply have been moving the forearm through the required ROM without cocontracting. These differences would, in turn, result in differences in the change scores. Those subjects who trained intensely, that is, those who maximally cocontracted agonist and antagonist, would exhibit large change scores while those who did not maximally cocontract would show little or no change, thus increasing the variability between change scores. This can be seen in the data with some subjects increasing RMS amplitude by over 300% while 0% change was seen in others.

Two sample t-tests assuming unequal variance were used to test for significance in the differences between trained and untrained arms in four conditions: BIR, BER, TIR, TER. In the TIR condition, the trained arm displayed significantly greater sEMG activity within the muscle (t = 2.71, P = 0.024; Fig. 5) when compared to the untrained arm. The change seen in the trained biceps during BIR was not found to be significantly greater than the untrained biceps (t = 1.55, P = 0.156; Fig. 6). For the external conditions, no significant differences were found between the changes observed in the trained and untrained arms at the P ≤ .05 level (BER: t = 1.64, P = 0.156; TER: t = 1.61, P = 0.156). Despite the lack of significance in the changes observed under the BER, BIR and TER conditions, the mean values observed for the trained arm were higher than for the untrained (Table 1).
Fig 5. Statistical graph showing change scores from pre to post test observed in the trained and untrained triceps with the mean and 95% confidence interval.
Fig 6. Statistical graph showing change scores from pre to post test observed in the trained and untrained biceps with the mean and 95% confidence interval.

\[ t(38) = 1.55, p = 0.156 \]
**Fig 7.** Typical sEMG data from a cocontraction trial showing bicep and tricep signals.

**Fig 8.** Typical sEMG data signal with superimposed RMS signal.
**Fig 9.** Typical pre and post test RMS signals of the trained tricep during TIR.

**Fig 10.** Typical pre and post test RMS signals of the untrained tricep during TIR.
Discussion

The purpose of this study was to determine whether resistance training using the antagonist muscle as resistance to the agonist muscle could enable an individual to generate more force in the antagonist muscle. If the training successfully increased the antagonist’s ability to provide resistance against the agonist, then antagonist resistance training (ART) could prove to be a feasible form of strength training. To determine whether there was an increase in force production by the antagonist, EMG data was recorded from agonist and antagonist muscles during isometric maximal voluntary cocontractions. Data was recorded prior to and immediately following the 6 week ART regimen. As was predicted, the differences in the pre and post testing data suggest that ART was able to increase the amount of neural activity observed in the trained triceps. Additionally, the EMG data from the untrained triceps, as well as both the trained and untrained biceps suggest increases in neural activity.

EMG amplitude in the left triceps after training was, on average, 92% higher than the amplitude before the training. Due to the fact that muscular force production and sEMG amplitude depend on the firing rate of each motor unit (MU), as well as the number of recruited MU’s (Farina et al., 2004), the increase in EMG amplitude is indicative of an increase in the force production of the triceps muscle. These EMG increases are consistent with previous short term strength training studies (McBride, Blaak, & Triplett-McBride, 2003), which also found increases in EMG activity after 6 weeks of dynamic training.

With the biceps typically displaying more sEMG activity in the present study, it is assumed that the subjects were able to produce a greater amount of force in the BB compared to the TB. Electrode placement may contribute to this difference, but the force data from the Rannelli et al. (2007) study reveal that initial strength values of the BB were on average 129%...
larger than those produced by the TB. The relatively small increase in sEMG activity observed in the trained bicep may be a result of this initial imbalance. As training progressed and the triceps increased the resistive force produced, they were able to increase the load placed on the biceps muscle, but not to a level of maximal bicep contraction. Due to the weaker nature of the muscles in the present study, the tricep contractions would be more likely to reach peak force production. The greater stress placed on the triceps would in turn stimulate neural adaptations comparatively larger than those resulting from less amounts of stress, namely that placed on the biceps. This is also supported by the Rannelli et. al (2007) study which showed a larger percentage increase in strength of triceps (7.4%) in comparison to biceps (4.6%). The larger neural adaptations observed in the triceps are seen through a larger increase in the sEMG amplitude of the triceps in comparison to the biceps.

The values presented thus far that display the increases in strength and EMG activity appear to be disproportional. With respective strength increases of 4.6% and 7.4% in the biceps and triceps, the 92% increase in EMG activity of the trained triceps seems quite large (92%). Accompanying this triceps EMG increase was a 39% increase in trained biceps EMG. However, these EMG increases were recorded during the internal resistance condition (CO). It is quite possible that the amount of isometric force produced during the cocontraction increased by much more than the 5-7% seen in the externally resisted contractions. This could be attributed to the initial learning of the task, as well as neural adaptations occurring after task familiarization. Both would result in increased force production (Fitts & Posner, 1967; Moritani & de Vries, 1979) which would be represented by increases in EMG activity, or possibly an increase in muscle CSA. Due to the short duration of training in this study, it is assumed that muscle CSA changes were negligible. Therefore, any increases can be attributed to neural adaptations, and so
larger increases in neural activity for CO in comparison to the externally resisted contractions are understandable.

The discrepancy between strength increases and external resistance EMG increases is much more feasible. With neural activity increases of 25% and 43% for the biceps and triceps respectively, the concomitant strength increases of 4.6% and 7.4% are more appropriate. These findings are in agreement with those of McBride et. al (2003) who found EMG increases of 31% with an associated 7.4% increase in 1RM bicep curl strength. The results of the present study suggest that, when compared with traditional resistance training, ART is as effective at eliciting neural adaptations in the target musculature.

The thought behind selecting right handed subjects for an exclusively left arm strength training program was to decrease the chance of cross education from trained to untrained arm. It has been suggested that the effects of cross education are greatest when the dominant arm is trained (Farthing, Chilibeck, Binsted, 2005). However, the presence of increased sEMG activity in the untrained dominant arm suggests that a certain level of cross education may have occurred in the present study. Hortobágyi, Lambert, and Hill (1997) reported similar cross education from left to right limb during a left quadriceps training program. The findings of the present research are supported by data suggesting that the level of cross education may be related to the degree of unfamiliarity of a task (Farthing & Chilibeck, 2003). With the lack of weight training experience present among the subjects, in addition to the novelty of sustained cocontractions throughout a range of motion (ROM), it is assumed that the task was quite unfamiliar. Also contributing to this cross education may be the strong neural involvement of the task. The idea that cross education has a neural basis has become well established over the years (Kamen, 2004). It seems reasonable to suggest, therefore, that cross education would occur during cocontraction
resistance training as the task involves a high level of neurological control. Additionally, due to this high neurological involvement, the idea that the cross education from left limb to right which is typically small, becomes more reasonable.

The data from this research shows that during the isometric internal resistance contractions, both bicep and tricep sEMG activity increased in the trained and untrained arm. However, within the external contractions, the untrained arms saw very little change from pre to post training. This might seem to contradict the proposed cross education explanation provided above. However, because contracting against external resistance is a more familiar task when compared to cocontraction, the likelihood of cross education would be significantly lower than for the unfamiliar cocontraction task, especially from the non-dominant to dominant limb. This data supports the three channel model of muscle control proposed by De Luca and Mambrito (1987). If the cocontraction of the agonist and antagonist muscles were simply due to the excitation of flexor and extensor motoneuron pools, then an equivalent increase in the sEMG in both BER and TER would be expected to accompany increases in the sEMG during BIR and TIR. This is based on the thought of specificity. If training resulted in adaptations to the flexion task, then these adaptations should be evident regardless of the source of resistance. However, the present data does not show this trend. In fact, the increases observed in the internal resistance conditions were much less than the increases seen under the external resistance conditions. A third command, coactivation, would explain this discrepancy. If the coactivation command has an excitatory affect on both flexor and extensor, than a resulting zero-torque joint stiffening would result from the contraction of both muscle groups, and hence, no movement of the limb. Adding in the excitation of either the flex or extend command would produce a net torque and cause limb movement. Applying the idea of specificity again, the excitation of the
additional command would result in adaptations to this command. For example, sustaining a cocontraction through a concentric contraction of the biceps would involve excitation of the cocontraction command, as well as the flex command. This would result in adaptations to both cocontraction and flexion commands. As this was the case during the training sessions of the study, it would seem appropriate for neurological adaptations to occur for all three commands.

![Diagram of De Luca and Mambrito's (1987) three channel model of muscle control.](image)

**Fig 11.** De Luca and Mambrito’s (1987) three channel model of muscle control. Flex and extend commands are reciprocally organized while coactivation is excitatory to both agonist and antagonist.

During the testing sessions, the contractions were isometric, and would therefore utilize only one of the three commands, depending on the conditions, according to the three channel model (De Luca & Mambrito, 1987). For example, during the bicep external resistance condition, the flex command would be active with the extend command inhibited via reciprocal inhibition. During the internal resistance conditions, the coactivation command would be exclusively active. Assuming only one command was used in the testing sessions – flex during
BER, extend during TER, and coactivation during CO – only the neurological adaptations occurring within that command would be evident in the data. Therefore, the lack of increase in sEMG activity in the untrained arm is explainable for the external contraction conditions in that the familiarity of the task would limit the potential for cross education from non-dominant to dominant arm.

The data provided by the current research has shown that ART is a plausible form of resistance training. Though the increases may be small, the sEMG amplitude changes from pre to post training are present, representing neural adaptations in the muscle which can in turn be interpreted as an increase in the force production of the muscles. This could be of great value to certain populations, such as injured or bedridden persons and the elderly. Injured persons, and in particular athletes with injuries preventing them from resistance training due to the inability to support the weight, through ART would be able to, at the minimum, maintain pre-injury strength, and possibly continue to increase their strength. Bedridden persons prone to muscular atrophy could employ ART techniques to prevent muscle loss while they are immobile. For the elderly, ART is an equipment free, effective form of exercise providing the neuromuscular benefits of any resistance training program, at zero cost. Due to the direction of muscle contraction for both agonist and antagonist, the forces about the joint, theoretically, would provide bone mineral density (BMD) benefits (Fig. 12). In this particular case, both biceps and triceps brachii are pulling the distal end of the humerus and the proximal end of the ulna together increasing the contact force between the two. Increased joint reaction forces, as are produced during ART, have been shown to improve or maintain BMD (Kohrt, Ehsani, & Birge Jr., 1997). The simple implementation of ART into an individual’s rehabilitation program could offset the bone mineral density decreases associated with chronic non-weight-bearing situations.
The research stemming from the current study could lead in various directions. Perhaps the most reasonable direction would be to determine the effects of a longer duration study on the sEMG and force production capabilities of the muscle. As well, it is important to examine the effects of ART on BMD and confirm the hypothesis of the experimenters. Additionally, research with subjects who have resistance training experience should be conducted to determine if ART is an effective form of training for experienced lifters. The effect on the male population is also of interest and should be examined. In order to address the issue of the large variability, an attempt should be made to control intensity during the training such as through intramuscular EMG analysis.
Conclusion

The results of the present study provide evidence suggesting that antagonist resisted training (ART) can improve the ability to cocontract. Additionally, ART may be an effective form of resistance training. Increases in sEMG amplitude are indicative of the neurological adaptations that occurred over the 6 week training period. The presence of improvements in the sEMG of the untrained arm may point toward the effects of cross education with the learning of an unfamiliar task. In support of a three channel model of muscle control, such as that presented by De Luca and Mambrico (1987), the data shows an increase in both trained and untrained arms within the internal resistance condition, while the external resistance conditions showed only improvements in the trained arm. ART appears to be an effective form of resistance training that could be beneficial to various populations, but further studies should look into its effectiveness in populations outside of females without resistance training experience.
References


APPENDICES
Application for Ethics Approval
StFX Human Kinetics Research Ethics Board

Project Title: Evaluating Antagonist Resistance Training

Project Start Date: Immediately upon approval

Investigators:
Megan MacGillivary, Luke Rannelli, Jordan Yurchevich

Supervisor:
Dr. Sasho MacKenzie
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smackenz@stfx.ca

Student Signatures:

________________________________________________________________________
Megan MacGillivray Date

________________________________________________________________________
Luke Rannelli Date

________________________________________________________________________
Jordan Yurchevich Date

Advisor Signature:

________________________________________________________________________
Signature Date
1. The Study

a) The topic of the proposed study is antagonist resistance training. We plan to investigate the effectiveness of this novel training technique among university aged women.

b) Muscular atrophy or gradual loss of muscle function and strength are direct products of decreased muscle unit activation (Hakkinen, Alen, Kallinen, Newton, & Kraemer, 2000; Ferrando, Tipton, Bamman, & Wolfe, 1997; Tesch, Trieschmann, & Ekberg, 2003). A decrease in muscle unit activation can occur for several reasons. General inactivity, prolonged bed rest, and living in an environment void of gravity are typical scenarios that lead to decreases in muscular strength and cross sectional area (Tesch, Berg, Bring, Evans, & LeBlanc, 2005). Extended time in these situations not only causes decreases in muscular strength and size but is also typically associated with a reduction in bone density (Shackelford et al. 2004). However, resistance training has been demonstrated to be an effective countermeasure for muscular atrophy. Resistance training typically results in physiological adaptation (Sale, 1988; Farina, Merletti, & Enoka, 2004), as well as rapid neuromuscular adaptation (Pucci, Griffin & Carafelli, 2006; Sale, 1988; Chilibeck, Calder, Sale, & Webber, 1998). Increases in maximal force produced are indicative of adaptation, whether neurological or physiological. Electromyographic analysis of the muscular electrical activity can provide an indication as to whether neural adaptation has occurred (Sale, 1988). Externally inducing a contraction in an antagonistic muscle has been shown as an effective means of producing a resistive force to the agonist, as well as improving the maximal force produced by the agonist and antagonist (Yanagi et al., 2003). Potentially, this same response could be achieved without the use of external electrical stimulation. A voluntarily contracted antagonist could serve as a resistive force. This would be a feasible means of strength training accessible to all, no matter what the environment.

The application of Antagonistic Resisted Training (ART) has real life benefits for people living on earth and for individuals whose occupations place them in the far realms of space. ART was born from this thought. It requires subjects to voluntarily contract an antagonist muscle to serve as the oppositional force for their agonist muscle. Should it be shown effective through this, and further studies, the benefits would be seen in a wide variety of preventative and rehabilitative situations.

c)


d) Quasi-experimental design with control.

e) In the study, a force transducer, and an electromyograph (EMG) will be used to collect both strength and muscle activity data from the participants. The EMG will collect data via two electrodes - one situated over the belly of the biceps brachii, the second over the lateral head of the triceps brachii. The force transducer will measure the force a participant exerts by pulling on a chain fixed to the ground.

During the test sessions, the participants will stand erect with their elbow bent at 90°, upper arm by their side, and palm facing up. This elbow angle will be maintained throughout the testing sessions. The participants will be instructed to perform a maximal isometric contraction of the biceps brachii and triceps brachii simultaneously for 5 seconds. Time will be monitored with a digital stopwatch. The data obtained from this simultaneous or co-contraction test will be referred to as the internal resistance data and/or the internal value.

Following the internally resisted contraction, an isometric Maximum Voluntary Contraction (MVC) will be performed using external resistance. The subject’s position will be the same as described above. The external resistance will be supplied by a chain. One end of the chain will be bolted to the ground, while the other will be connected to a handle. Subjects will be instructed to maximally contract the biceps brachii against the resistance of the chain. A force transducer will measure the tension in the chain. The contraction will last 5 seconds. The data
obtained from the contractions against the handle of the chain will be referred to as the external resistance data and/or external value.

The third component of the testing will be the triceps brachii strength test. The handle/chain/force transducer setup will be inverted so that the top of the chain is bolted to a rigid brace on the wall. The handle end of the chain will hang vertically down. Subjects will stand in the same position described above; except now the palm will be facing down. Subjects will be instructed to exert an isometric MVC by pulling down on the handle for 5 seconds. Testing will be done on both the right and left arms, with the right arm serving as the control group, the left being the experimental group. Two testing sessions will be performed 6 weeks apart: the first test before the training, and the second test immediately following the 6-week training program. All data collected will be stored for future analysis.

Root mean square (RMS) of the EMG signals will be computed using the 0.5 seconds of data lying to either side of the highest EMG peak. Using this second will allow for the removal of any activity ‘build up’ towards a maximal contraction, as well as to eliminate any premature relaxation. The internal resistance data will then be compared to the external resistance data to give a percent MVC value. The expression of the internal value as a percent of the external value will help to remove any extraneous factors that may lead to changes in EMG over the period of the study. The data will then be analyzed. Various inferential and descriptive statistics will be used to test for significant differences. The force transducer data will be averaged over the two trials and then statistically analyzed by means of a 2 x 2 ANOVA analysis.

f) The methods used above were chosen as they are consistent with previous research within the field. The most appropriate means of statistically analyzing the data was chosen to test for significant differences.

g) The data will not be disseminated in any way other than in journal publications and at scientific conferences.

2. The Subjects

a) The subject population will be university-aged females.
b) We aim for a sample size of 30 subjects.
c) The subjects will be recruited based on three criteria: no weight training within the last six months, subjects must be right handed, must not have a pre-diagnosed neurological or musculoskeletal disorder.
d) The recruitment will be done through posters placed around the St. Francis Xavier University campus, mass emails, as well as word of mouth. First and second year classes that typically have students from a wide range of programs will be targeted for word of mouth recruitment.
e) There will be no relationship between researcher and participant.
f) We do not foresee any conflicts of interest or ethical difficulties with our proposed participants and the nature of this study.
3. Research Setting

This study will be conducted within the university.

4. Invitation to Participate

We intend to use the Invitation to Participate letter to explain the nature and purpose of this study to the participants. Please see the attached Invitation to Participate letter we plan to use.

5. Transcriptions of Interviews or of Group Discussions

This study will not be using interviews or group discussions, and therefore, no transcription will be required.

6. Plain Language Usage

a) We will assume a literary competence equivalent to that of students graduated from secondary school (i.e. Grade 12 literacy level).

b) Although reading comprehension should not be an issue within this research, great care will be taken to explain all terms that may subjects may be unfamiliar with, especially in the Invitation to Participate letter.

7. Deception

a) No, this study does not involve deception. All methods and reasoning will be described to each participant.

8. Recompense for Research Participants

The subjects will not be offered recompense for participation in the study.

9. Potential Costs for Participants

There is potential in this study for the participant to experience some muscle soreness after the first few sessions of the strength training program. This is normal at the onset of strength training programs, and should not occur past the third session. The affects of the stresses will be minimized through the use of a warm-up prior to the exercises, as well as stretching immediately following the exercises.
APPENDIX B – INVITATION TO PARTICIPATE AND CONSENT FORM
Evaluating Antagonist Resistance Training

Invitation and Consent

Introduction:
Due to barriers related to lack of or inadequate facilities or equipment, many people do not participate in resistance training. All muscles in the body come in opposing groups. For example, the muscles on the front of the upper arm can bend the elbow when they are working (contracting), while the muscles on the back of the upper arm can straighten the elbow when they are working (contracting). The muscles that cause an intended movement are called agonists, and the muscles that can produce the opposite movement are called antagonists. Co-contraction, the simultaneous contraction of both the agonist and antagonist muscles, could act as a beneficial form of resistance training if the antagonists are able to provide sufficient resistance for the agonistic muscles. For example, contracting the muscle that bends the elbow at the same time you are contracting the muscle that straightens the elbow. This form of resistance training could benefit a very large population because no external equipment would be required.

You are invited to take part in a research project that involves the evaluation of co-contraction as a means of resistance training. The study will be conducted at St. Francis Xavier University in the Biomechanics Laboratory. Participation in the study is completely voluntary and you may choose to withdraw from the study at any time.

Purpose of the Study:
The purpose of this study is to gain a general understanding of the potential of co-contraction to act as a sufficient means of resistance training. The research project will analyze the potential of the antagonistic triceps to act as resistance for the agonistic biceps. The principle investigator is Sasho MacKenzie, and the co-investigators Luke Rannelli, Jordan Yurchievich, and Megan MacGillivray, are using individual aspects of the overall project for independent thesis studies.

Study Design:
The study will take place in three main stages.
1. Electromyography (EMG) and force measurement testing will be used to determine the maximal voluntary isometric contraction using external resistance and co-contraction on the biceps and triceps. Each subject will perform two 5 second contractions using external resistance and two 5 second contractions using co-contraction for each arm.
2. A 6-week training program consisting of three 20-minute workouts per week will be employed. There will be eight sessions offered per week, but you will only be required to attend three sessions which are on different days.
3. Electromyography (EMG) and force measurement testing will again be used to determine the maximal voluntary isometric contraction after the training program. External resistance and co-contraction measurements of the biceps and triceps will again be taken with each subject performing two 5 second contractions per arm per test.
**Time commitment:** The initial testing time for each subject will be roughly 25 minutes. During the six week training period, the subjects will come in for 20 minutes, three times per week. Their accumulative time commitment over the 6 weeks will be approximately six hours. At the end of the training period the subjects will be re-tested which again should take approximately 25 minutes per subject. The full time commitment from each participant will be 7-8 hours.

**Possible risks and discomforts:** It is possible that you will experience some muscle soreness from the initial workouts, however as the program continues, these effects should subside.

**Possible Benefits:** It is possible that through this strength training program that the participants will experience strength increases.

**Anonymity:** Confidentiality will be maintained throughout the course of the study; only the researchers and the supervisor will have access to the data. Data will be stored in a computer located in the supervisor’s lab. Data will not be associated with the participant; each participant will be assigned a subject number. Upon completion of the study, all names will be removed from the data.

**Voluntary Participation:** You are able to withdraw from the study without penalty at any time. Your participation is completely voluntary. If at any point you wish to withdraw from the study please contact one of the researchers or the supervisor. You may phone, e-mail or approach us at anytime. The data collected from you up until the point of withdrawal will be kept and utilized in the study.

**Data:** The data collected from the research study will be archived after the reports are published.

**Questions:** You have the right to inquire about this research project at any time before, during and after the research is conducted. If you have any questions or concerns about this project feel free to contact any of the researchers or the supervisor.

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Evaluating Antagonist Resistance Training
Consent Form

I have received a copy of the Invitation to Participate for the research project entitled Evaluating Antagonist Resistance Training, have had the opportunity to read the information provided as well as have it explained by the researchers. I have had any questions that I may have answered.

I agree to participate in this research project, and understand that any information collected will be handled confidentially by only the researchers and their faculty supervisor. I understand that my participation is entirely voluntary, and that I have the right to withdraw from the study at any time, should I wish to do so as outlined in the Invitation to Participate.

Participant:

________________________________________
Name

________________________________________  __________________________
Signature                           Date

Researcher:

________________________________________
Name

________________________________________  __________________________
Signature                           Date

PARTICIPANT COPY
Evaluating Antagonist Resistance Training
Consent Form

I have received a copy of the Invitation to Participate for the research project entitled Evaluating Antagonist Resistance Training, have had the opportunity to read the information provided as well as have it explained by the researchers. I have had any questions that I may have answered.

I agree to participate in this research project, and understand that any information collected will be handled confidentially by only the researchers and their faculty supervisor. I understand that my participation is entirely voluntary, and that I have the right to withdraw from the study at any time, should I wish to do so as outlined in the Invitation to Participate.

Participant:

________________________________________
Name

________________________________________  __________________________
Signature  Date

Researcher:

________________________________________
Name

________________________________________  __________________________
Signature  Date

PLEASE DETACH AND RETURN THIS COPY TO ONE OF THE RESEARCHERS
APPENDIX C – TRAINING REGIMEN
Week One:

- Concentric: 2 sets x 12 reps
- Eccentric: 2 sets x 12 reps
- Combination: 2 sets x 8 reps

Week Two:

- Concentric: 2 sets x 12 reps
- Eccentric: 2 sets x 12 reps
- Combination: 3 sets x 8 reps

Week Three:

- Concentric: 2 sets x 6 & 6 (½ reps)*
- Eccentric: 2 sets x 12 reps
- Combination: 3 sets x 9 reps

Week Four:

- Concentric: 3 sets x 6 & 6 (½ reps)
- Eccentric: 5 sets x 6 reps
- Combination: 3 sets x 6 reps

Week Five:

- Concentric: 3 sets x 6 & 6 (½ reps)
- Eccentric: 4 sets x 6 reps
- Combination: 3 sets x 6 reps

Week Six:

- Concentric: 3 sets x 6 & 6 (½ reps)
- Eccentric: 3 sets x 6 reps
- Combination: 3 sets x 6 reps

* 6 reps from full extension to 90° flexion, and 6 reps from 90° flexion to full flexion

Notes:
- weeks one and two: all exercises had forearm supinated
- weeks three through six: eccentric contractions start with palm supinated and will have 90° medial rotation; combination contractions start at 90° medial rotation and rotated laterally to full supination