AN EXAMINATION OF BALLISTIC MOVEMENT AND BALLISTIC RESISTANCE TRAINING

NICOLE AGNES DINN

An Examination of Ballistic Movement and Ballistic Resistance Training

By

Nicole Agnes Dinn

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CO-AUTHORSHIP STATEMENT

The following statements clearly identify my role in the development, execution and preparation of this thesis:

1. Design and identification of the research proposal. The research idea and proposal was discussed with Dr. Behm and under his guidance I obtained approval for the study. Dr. Behm and I collaborated on research methodology, which consisted of ideas from previous studies by Dr. Behm, and from my own ideas.
2. Practical aspects of research. Raw data were collected solely by me.
3. Data analysis. Under the supervision of Dr. Behm, I performed all data analysis procedures.
4. Manuscript preparation. Under the supervision of Dr. Behm, I prepared this manuscript for submission.

THESIS STRUCTURE

This thesis was prepared in a non-traditional, manuscript format.

LIST OF ABBREVIATIONS

1RM	One Repetition Maximum
AG1	Initial Agonist Burst
AG2	Second Agonist Burst
ANT1	Initial Antagonist Burst
ANT2	Second Antagonist Burst
AntI	Antagonist Inhibition
AT1	Initial Testing Bout – Post-training
AT2	Second Testing Bout – Post-training
BT1	Initial Testing Bout – Pre-training
BT2	Second Testing Bout – Pre-training
CTRL	Control Group
DYN	Dynamic Training Group
EMG	Electromyography
FT	Fast Twitch
ICC	Intraclass Correlation
iEMG	Integrated Electromyography
ISO	Isometric Training Group
MVC	Maximum Voluntary Contraction
PM	Peak Extension Movement
RFD	Rate of Force Development
ROM	Range of Motion
Wisk	Isokinetic Work Output

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ABSTRACT

Training specificity refers to exercises designed to improve a particular function or movement in a sporting situation. Training specificity is advocated for many sports and includes velocity, joint angle and range of motion specific components. The neural adaptations that occur with training include changes in recruitment and rate coding, antagonist co-contractions, and cross-education. During explosive contractions, which are often seen in a sport setting, muscle activation as monitored with electromyography (EMG) will exhibit a triphasic burst pattern. This pattern serves to augment the movement being produced. The present study included the use of velocity-specific training and the intent to contract explosively to improve punch training. Subjects were measured on force production, EMG, movement and reaction time, and coordination. Main findings included a decrease in movement time with dynamic training, and impaired coordination with isometric training. Neural adaptations, demonstrated by changes in EMG, were also found. Because of its specificity of movement, dynamic training may be a more appropriate method to improve punching speed and co-ordination for martial artists and boxers.

INTRODUCTION

Training that is specific to an athlete's sport is a vital component of any strength and conditioning program. Such a concept is not new – training specificity is widely used by coaches and athletes with success in many sports, such as sprinting (Young et al.2001), and baseball (DeRenne et al.2001), among others. In considering sport-specific training, the velocity (Coyle et al.1981) and movement (Young et al.2001) should closely as possible match the sport setting in order to achieve desirable results. Typically many sports involve high-velocity, explosive movements, and ballistic contractions (Zehr and Sale, 1994).

Research on ballistic movements has both supported (Paddon-Jones et al.2001) and refuted (Liow and Hopkins, 2003) claims in the efficacy of their inclusion on sports training programs. Paddon-Jones et al.(2001) saw improvements in torque output during isometric, eccentric and concentric muscle actions (contractions) in subjects who trained eccentrically at a fast velocity, but not in those who trained at a slow velocity. Contrastingly, Liow and Hopkins (2003) have shown slower training as opposed to ballistic movements to be more effective, as seen in improvements during the acceleration phase of a sprint in kayaking.

Behm and Sale (1993) investigated the notion of attempted ballistic training and reported that it was the *intent* to contract explosively, and not the actual movement itself, that is a key factor in improving peak torque and rate of torque development in the lower leg muscles. One limitation to that study was the lack of a separate control group, given the fact that both legs of the subjects were involved in either high speed or isometric training. Therefore, a cross-education effect may have confounded their results. A more recent study by Olsen and Hopkins (2003) using a ballistic intent to contract, found subjects who trained using conventional and isometric ballistic kick training increased their speed, but decreased the amount of force produced.

The purpose of the present study is to determine whether it is the intent to contract at a high velocity (using isometric training) or the actual movement speed (using dynamic training) that determines the greatest gains in strength, reaction and movement time, as well as other velocity-related performance measures. Changes in electromyographic (EMG) activity and co-ordination will also be examined in attempt to understand possible mechanisms. To remove possible confounding effects of cross-education, subjects will train with a single arm. Additionally a control group is implemented in the study design to examine the overall effects of the training program.

A Comparison of Ballistic Movement and Ballistic Intent Training on Muscle Strength and Activation

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RESEARCH QUESTION AND HYPOTHESIS

Research question:

- Does training with the intent to contract explosively provide similar, better or less benefits than dynamic explosive training for strength and movement velocity?

It is hypothesized that:

- Training with the intent to contract explosively will produce similar benefits as performing dynamic high-velocity resisted movements, in terms of isometric force production, integrated electromyography (EMG), and movement and reaction time. Training with dynamic high-velocity resisted movements will provide more significant changes in intermuscular co-ordination (i.e. agonist-antagonist coupling).

REVIEW OF LITERATURE

1. Introduction

Resistance training is widely used among virtually all competitive athletes, and has become increasingly popular among recreational athletes and non-athletes as well. The benefits of resistance training are numerous: increased muscular strength (Aagaard et al., 2002), and size (Hakkinen et al., 2001); prevention of muscular atrophy (Kubo et al., 2004); and improvements in motor performance and balance (Hauer et al.,2002) are just some of the advantages to resistance training. With respect to sports, not only does resistance training increase muscular strength and size – a key factor in a multitude of sports – but it may also improve functional performance within a sport itself; that is, resistance training specific to a sport can improve the performance of the sport (Kraemer et al.,2000).

For sport-specific resistance training to be effective and for athletes to receive the most benefit, velocity and movement should be similar to that performed in the sport. Since many sports typically display explosive or ballistic contractions, it would be assumed that training programs involving these movements might result in improved sports performance. Zehr and Sale (1994) defined ballistic actions to be "those movements that are performed with maximal velocity and acceleration." While numerous studies have examined the effect of ballistic training, the results have been mixed. Paddon-Jones et al.(2001) saw improvements in torque output during isometric, eccentric and concentric muscle actions (contractions) in subjects who trained eccentrically at a fast (180 °/s) velocity, but not in those who trained at a slow (30 °/s) velocity. Improvements in the use of velocity-specific training programs to increase force output in jumping (Newton et al., 1999) and peak power in shoulder throwing (Dalziel et al., 2002), have also been found. Still, others have shown slower training as opposed to ballistic movements, to be more effective, as seen in improvements during the acceleration phase of a sprint in kayaking (Liow and Hopkins, 2003).

Behm and Sale (1993) have shown that it is the *intent* to contract explosively, and not the actual movement itself, that is a key factor in improving peak torque and rate of torque development in the leg muscles. One limitation to that study was the lack of a separate control group, given the fact that both legs of the subjects were involved in either high speed or isometric training. A cross-education effect may have confounded their results. A more recent study by Olsen and Hopkins (2003) using a ballistic intent to contract, outlined comparable results to that of Behm and Sale. They demonstrated an increase in kicking speed with the use of both conventional (dynamic) and isometric ballistic kick training.

Because of conflicting findings reported in previous literature, this review will attempt to clarify some of the key points surrounding ballistic contractions. It will examine the role of training specificity, neuromuscular characteristics of ballistic contractions, and the role of peripheral versus central adaptations to ballistic training.

2. Training Specificity

Training specificity is an important consideration for athletes, and refers to exercises designed to improve a particular function or movement in a sporting situation. An example of this would be performing jump squats to improve jumping capabilities. A further example of this would be to practice sporting movements at the speed with which they would normally be performed. This is known as velocity specificity. Training specificity is advocated for all sports, for example tennis, ski jumping (Muller et al., 2000), baseball (DeRenne et al. 2001), and sprinting (Young et al., 2001). When discussing training specificity, the velocity and type of movement need to be considered, along with the type of contraction and the angle at which the movement is being performed. For example, Young et al. (2001) studied the effects of various types of sprint training on speed and agility tests among three groups. One group served as a control; a second group trained by sprinting in a straight line only; and a third group trained by sprinting in various directions. The group participating in the straight sprinting significantly improved only in straight sprinting, but not in agility tests. Conversely, the group performing agility training showed improvements in agility tests, but not in straight sprinting. This study clearly demonstrates the necessity of training programs that are specific to the desired performance goal. Rasch and Morehouse (1957) compared the effects of isometric versus isotonic training on muscular strength and hypertrophy. Subjects were divided into either an isometric or isotonic training group, and performed three sets of five repetitions of both elbow flexion and shoulder press movements over a six week period. Testing was done isometrically for both elbow flexion and shoulder press force production capabilities. The position of the body during testing was the same for isometric training. Subjects who trained isotonically showed greater increases in isometric muscle strength and size than did those who trained isometrically; thus, a lack of training specificity was demonstrated.

A. Joint-Angle and Range of Motion Specificity

The concept of range of motion (ROM) or joint-angle specificity refers to the notion that strength gains diminish as the training angle (or ROM) deviates from the task angle (or ROM). For example, a rower who trains through a 120° ROM would not experience the most effective training effects if he or she only trained through a 60° ROM, and where this range is within the total physiological range.

Kitai and Sale (1989) demonstrated joint-angle specificity in women who trained isometrically for six weeks at an ankle joint of 90°. Before and after the training program, voluntary and evoked isometric forces were measured between 5° and 90°. An increase in voluntary strength was seen at the training angle, and at 5° from the training angle, in both dorsiflexion and plantarflexion. No increases in evoked twitch torque were seen at any angle tested. This indicated that the angle-specific training effect was under neural control. Weir et al. (1995) showed angle specificity with eccentric muscle actions (contractions) after eight weeks of eccentric leg extension training. Isometric strength was measured at several knee joint angles, as was eccentric 1 repetition maximum (1RM). After training through a range of 75°, isometric strength was improved at 45° and 75°, but not at 15°. Eccentric 1RM also increased after training. Barak et al. (2004) examined the effects of various training range of motions and contraction types on rate of force development (RFD) and peak extension moment (PM). Women trained fast (90°/s) or slow (30°/s), concentrically or eccentrically, in the range of 30° - 60° knee flexion. After six weeks of training, significant increases in RFD at 45°, and isokinetic work output (Wisk) at ranges 60-85° and 30-60° were seen, and PM was increased across testing angles (10, 45, and 80°) in the groups training eccentrically. The results demonstrate specificity in terms of range of motion (seen in Wisk results) and in type of contraction (seen in PM results) in a training program.

Weir et al. (1997) did not demonstrate joint angle specificity after eight weeks of concentric leg extension training. Subjects were tested isometrically at various knee joint angles, and completed a 1 repetition maximum (1RM) test, before and after the eight-week training program.

Isometric strength increases were seen in all joint angle tests, and an increase in 1RM was also shown. Massey et al. (2004) also demonstrated conflicting results to those of Barak et al. (2004) and Kitai and Sale (1989). Massey et al. (2004) trained subjects in the bench press twice weekly for ten weeks. One group trained with a full ROM, while the other group trained with a partial ROM. Here, partial ROM was defined as a movement "beyond the sticking point 2 to 5 inches from full extension of the elbows" (Masset et al., 2004). In post-training 1RM tests through a full ROM, both groups significantly improved their 1RM and no differences were seen between training groups.

While angle of training has an effect on transferability of strength gains to testing situations, it appears that contraction mode is also involved in angle specificity in training, as specific training-induced changes have been shown with isometric and eccentric training, but not with concentric training.

B. Training Mode Specificity

Training mode specificity refers to the idea that when one performs exercise in a specific manner, performance improvements would be seen when tested in the same manner as which one had exercised. For example, if one trained a squat movement on a regular basis, improvements in that person's 1 repetition maximum (1RM) squat would be more likely to result over improvements in the person's 1RM leg press. It could also be said that training mode specificity refers to showing improvements in dynamic strength, but not isometric strength, after dynamic training.

Kanehisa and Miyashita (1983) examined the effects of isokinetic and isometric training on static strength and dynamic power. Subjects were tested isometrically at various elbow joint angles, and maximal power of elbow flexors was also measured using various masses. Subjects first trained isometrically for eight weeks at various elbow joint angles specific to those in the testing procedure. They were then divided into either fast or slow isokinetic training groups (training range 20° - 130°) for six more weeks of training. Isometric strength and power were increased during the first eight weeks of training. During the second phase of training, the fast training group showed increases in power with lighter weights, while the slow training group showed increases in power with heavier weights. No changes in isometric strength were seen after the dynamic training.

Duchateau and Hainut (1984) reported increased maximal shortening velocity when subjects trained dynamically but not isometrically, and maximum muscle power was higher after isometric training than dynamic training. More recently, Folland et al. (2005) demonstrated increases in isometric strength with isometric training. Increases in isokinetic strength were seen across a variety of velocities with isokinetic and isometric training.

Whereas isometric resistance training may be advantageous for rehabilitation, increasing strength at a specific angle within a ROM or other similar application, the training adaptations do not transfer effectively to the dynamic needs of most sports or activities of daily living. It appears that dynamic training may transfer easier to isometric training, but isometric training does not always result in increases in dynamic strength.

C. Velocity Specificity

Velocity-specificity training in a sport setting implies that training is conducted at the speed and power with which one would use during the task. While this seems logical, the research on the viability of velocity-specific training is somewhat conflicting. A popular machine for examining the effects of velocity-specific training has been the isokinetic dynamometer, where strength is measured in peak- or angle-specific torque (Pereira and Gomes, 2003). The resistance applied in an isokinetic dynamometer stays constant throughout the whole movement, whereas isotonic movements provide a variable resistance as the movement is executed.

Work by Coyle et al. (1981) showed various improvements with respect to training velocity. Three groups trained with isokinetic leg extensions three times per week for six weeks, with similar total work done across three groups. One group performed five sets of six maximal repetitions at 60°/s (slow). A second group trained at 300°/s (fast) and did five sets of 12 repetitions. A third group completed a mix of fast and slow training. Each group was tested before and after the six-week training program, which consisted of performing two-legged extensions at 0, 60 180, and 300°/s. The 'slow' group showed improvements of 20, 32 and 9% in the 0, 60 and 180°/s trials, respectively, and did not significantly improve in the 300°/s trial. The 'fast' group improved by 15-24% in all velocities. Similar results were seen by the 'mixed' group, although they showed greater improvements in the 60 and 300°/s trials than the 180°/s trial. Similar results were seen in an experiment by Paddon-Jones et al. (2001). Subjects trained elbow flexors isokinetically for ten weeks, with either fast (180 °/s) or slow (30 °/s) contractions. After ten weeks, the fast group produced significant increases in torque during eccentric and concentric muscle actions (contractions) at speeds of 180 °/s. Improvements in isometric torque and eccentric torque (30 °/s) were also demonstrated. For the slow group, muscle torque was not significantly improved. Contrasting both of these studies is Caiozzo et al. (1981), who showed the high velocity group did not improve torque at all velocities tested, whereas the slow velocity group did. The slow velocity group improved knee extension torque on a range of speeds from 48 °/s to 240 °/s, while the fast velocity group improved in the range of 144 °/s to 240 °/s. The authors of the study attributed these findings to motoneurone activation increased when training at 96 °/s.

Velocity-specific effects have been seen with isotonic training. Liow and Hopkins (2003) had trained kayakers participate in one of three groups: slow weight training, explosive weight training, or a control group. Subjects trained twice weekly for six weeks, at approximately 80% of their one-repetition maximum, and also performed exercises specific to their sport throughout the training program. Performance in a 15m kayak sprint before and after the training program was also measured. Weight training, regardless of which group the subjects were in, produced significant improvements in sprint time. The slow weight-training group produced more significant improvements in sprint time than the explosive sprint group. The authors mentioned that the slow weight training might be more effective for acceleration of movement, due to a high force production throughout the entire length of the stroke. Other researchers (Cronin et al., 2001; McBride et al., 2002) have shown improvements with slower weight training than explosive lifting, in netball players. Cronin et al. (2001) showed that females training at a velocity of 0.3m/s at 80% of their 1RM had improved peak power output and mean weight lifted, when compared with those training at 60% of their 1RM and at 0.4m/s. A possible explanation for this would be that intensity and not velocity of lifting was the primary factor in determining differences seen between groups. The speed at which weight training was performed did not seem to be very different between groups, given a 0.90 m/s difference in velocity. Had the 60%1RM group trained with less intensity, the lifting speed may have increased, and further differences may have been demonstrated. McBride and colleagues (McBride et al., 2002) examined the effects of heavy- and light-load jump squats on various speed, strength and power tests. Improvements in velocity-related components were seen in the light-load group, while the high-load group showed improvements in strength- and power-related components.

While velocity of movement is arguably an important factor in determining what gains are made in training, some research has shown that it is the intent to contract explosively that may be more important that the actual movement or velocity. Behm and Sale (1993) trained 16 subjects in unilateral ankle dorsiflexion, thrice weekly for 16 weeks. Subjects were trained so that one limb trained with isometric contraction, while the other limb trained with high-velocity, at 300 °/s. Both isometric and high-velocity contractions were performed explosively. Both limbs improved on peak torque at all velocities, but more markedly at 300 °/s. Voluntary rate of isometric force development rate also improved in both limbs. It was concluded that the primary factor for eliciting gains in velocity-specific training was the intent to contract explosively, as opposed to performing the actual explosive contraction; it is the intrinsic rate of force development that played a crucial role.

A second study investigating the attempt to contract explosively on force production was conducted by Olsen and Hopkins (2003). They recruited trained martial artists and placed them into either a control or an experimental group. The experimental group performed conventional resistance training for eight weeks (twice weekly, two to three sets per week), followed by a combination of conventional weight training (twice weekly, two sets per week) with attempted ballistic training (three days per week, four to five sets of ten repetitions per leg), for ten weeks. A significant increase in kick force was seen after the first eight weeks of training. The ballistic training decreased front kick force but increased movement speed in palm strikes and side kicks. The ballistic training showed more improvements in highly skilled athletes compared to those with lesser skill. Athletes with less skill will need to develop neural coordination, and thus spend their energy maintaining balance and developing movement-execution patterns, as opposed to generating force and velocity with training.

It can be concluded that neural adaptations play a strong role in training-specific adaptations. This is demonstrated by the lack of angle specificity with evoked contractions (Kitai and Sale, 1984) and the predominant adaptations attributed to the intent to contract explosively (Behm and Sale, 1993).

3. Neural Adaptations to Resistance Training

While several reasons are cited for having an impact on improvements related to resistance training, neural adaptations are a significant component (Behm, 1995; Sale, 1988). Neural adaptations refer to changes in recruitment of motor units, rate coding, and co-activation of antagonist and synergist muscle groups, among other changes. Frequently, neural adaptations are assessed by electromyography (EMG), which can reflect, among other factors, a combination of rate coding and recruitment (Aagaard, 2003). Neural adaptations are primarily responsible for strength increases in the first 8-12 weeks of training, after which time subjects demonstrate an enhanced ability to recruit motor units as they become more trained (Sale, 1988). An increase in the recruitment of high-threshold motor units may allow a greater force to be developed, possibly due to more fully activated prime movers, as well as better coordination of the muscles involved (Sale 1988).

A. Recruitment and Rate Coding

Muscle fibers are recruited according to the size principle (Henneman et al.,1965a and 1965b), which states that motor units are recruited according to the size of the soma, with Type I fibers being recruited first (producing the smallest amount of force), and Type II fibers being recruited later (producing a greater amount of force). In order to recruit high-threshold (Type II) fibers, high intensity exercise must be carried out.

In terms of contraction type, eccentric muscle actions (contractions) preferentially recruit a greater number of fast twitch (FT) units than concentric contractions (Hortobagyi et al., 1996). Hortobagyi et al., (1996) demonstrated a three-fold increase in eccentric strength when compared to concentric strength, and showed that Type II muscle fiber area increased to about two times its original size after eccentric compared to concentric training. This can be attributed to greater force produced during eccentric muscle actions (contractions) (Higbie et al., 1996; Hortobagyi et al., 1996) resulting in a greater stimulus for strength and hypertrophy. Concentric contractions were also found to produce activation of FT fibers (Hakkinen et al., 1985). Hakkinen et al., (1985) trained subjects for 24 weeks where subjects performed jumping exercises without extra load and with light weights. Subjects also participated in strength training at 60 – 80% of their 1RM for the extensor muscles, trunk and arms. Increases in maximal average forces, overall EMG of the leg extensors, maximal isometric force, and fast force production were found. The recruitment of FT fibers also increased with the improvement of fast force production. Although increases in maximal strength were minimal, the authors attribute this to a lack of high loads used in training.

A term to describe the firing rate of motor units is known as rate coding. Van Cutsem and Duchateau (1998) found that increases in maximal firing rate and the presence of doublets contributed to an increased speed during ballistic contractions and increases in maximal voluntary contractions (MVC). Del Valle and Thomas (2005) found similar results when subjects performed MVCs. The preceding muscle state has an impact on whether an increase in firing rate was shown during MVCs. Van Cutsem and Duchateau (2005) had subjects perform ballistic contractions after maintaining a contraction of approximately 25% of their MVC, and found a decrease in firing rate, doublet discharge, and torque development. Therefore, the ballistic contraction performed after a low-intensity isometric contraction may not be as forceful as one performed from a resting state.

B. Antagonist Inhibition and Co-Contractions

Activity of the antagonist muscle is seen in both rapid explosive movements (Desmedt and Godeaux, 1979) as well as slow concentric and eccentric muscle actions (contractions) (Aagaard et al., 2000). Antagonist activation is thought to be a protective mechanism for the joint involved in the action (St. Clair Gibson et al., 2001; Sale 1988), but has been seen to diminish with prolonged training (Aagaard et al., 2000; Hakkinen et al., 1998; Kellis and Baltzopoulos 1997; Sale 1988;). As the trainee becomes increasingly familiar with the movement pattern, activity of the prime movers will increase (Hakkinen et al., 1998), and overall activity of the antagonist will decrease. The reduction in antagonist co-contraction improves coordination, and possibly allows a greater relative force output and increase in strength. Hakkinen et al., (1998) showed that untrained individuals could decrease antagonist activation in the leg flexor muscles following 6 months of training involving medium-to-high loads and explosive concentric contractions followed by the eccentric lowering phase. Activity of the biceps femoris (acting as the antagonist) was shown to decrease with training in the elderly male and female groups (Hakkinen et al., 1998), thus giving indication of decreased antagonist activity with training.

Antagonist inhibition is specific to the type of contraction involved. Activities involving ballistic or explosive concentric contractions may also have higher levels of antagonist co-activation (Sale, 1988). This can be a beneficial aspect among sprinting athletes, and other athletes where ballistic movement is present. The explosive contractions used in sprinters can trigger an explosive co-contraction of the antagonist muscles via the stretch-shortening cycle (SCC), which serves as a joint-protecting mechanism near the end of the range of motion.

C. Unilateral Training and Cross Education

Unilateral strength training (training with one limb) may be of benefit to those with injury in the other limb and want to maintain their activity level. The basis of this claim is that strength training in one limb may produce significant strength increases in the untrained limb (Cannon and Cafarelli, 1987; Rasch and Morehouse, 1957). This effect has been termed cross-education, and has been the subject of much study.

Rasch and Morehouse (1957) compared isometric versus isotonic resistance training over six weeks. Significant increases in strength were seen in the trained and untrained arm, in both the biceps brachii curls and shoulder press, for the isotonic group. Ebersole et al., (2002) also found significant increases in elbow flexor strength in the untrained limb following eight weeks of training at 80% of their 1RM. A possible explanation for these findings could be the necessity to incorporate a more complex movement, such as a multi-articular exercise, which would require more coordination and central command.

The use of dynamic training has shown to be effective in promoting cross-education, as demonstrated by Housh et al., (1996). Subjects trained their quadriceps for eight weeks at 80% of their 1RM, performing three to five sets of six repetitions, followed by eight weeks of detraining. Training resulted in significant increases in concentric strength in the trained and untrained leg immediately post-training and after the eight-week detraining period. Evetovich et al., (2001) saw significant increases in concentric peak torque development for both trained and untrained legs after 12 weeks of training three times per week, performing six sets of ten leg extensions.

Hortobagyi et al., (1997) saw greater improvements in cross-education with eccentric than with concentric training. Subjects exercised the left leg extensors for 12 weeks, using an isokinetic dynamometer, at a speed of 62 °/s. Concentric training improved eccentric strength by 22%, while concentric strength improved by 30%. Eccentric training improved concentric strength by 39% and eccentric strength by 77%. Additionally, surface EMG activity of the vastus lateralis increased by approximately 2.5 times from pre- to post-training in the trained leg. However neither strength nor EMG changed in the contralateral leg. Farthing and Chilibeck (2003) compared cross-education in the elbow flexors after eccentric training at different velocities. Subjects served either as a control, or trained a single limb at 30°/s or 180°/s on an isokinetic dynamometer, thrice weekly for eight weeks. Pre- and post-training, measures of peak torque during concentric and eccentric elbow flexion at 30°/s and 180°/s were taken in each arm. Eccentric peak torque increased in the untrained arm for the fast training group when tested at 180°/s. No change was seen for the untrained arm in the slow training group, when tested at 30 or 180°/s. For the trained arm, concentric peak torque was similar across both testing sessions, while eccentric peak torque was greater during testing at 180°/s. Therefore, eccentric muscle actions (contractions) of the untrained limb exhibit velocity specific training adaptations.

4. Muscle Properties and Ballistic Movement

<u>A. Ballistic Contractions and the Triphasic EMG Burst Pattern</u>

Electromyography during ballistic contractions exhibits different characteristics compared to that of slower contractions. Slower, ramp contractions that produce gradual increases in force will show continual agonist activation (Hallet and Marsden, 1979). The triphasic EMG burst pattern that is typical of ballistic contractions occurs from the firing of the agonist and antagonist muscles of the limb executing the contraction. Specifically, a triphasic EMG burst pattern will display an initial burst from the agonist muscle, followed by an antagonist burst/agonist silent period, and a repeat of the agonist muscle burst (Watcholder and Altenberger, 1926, in Zehr and Sale, 1994). The timing at which specific components of the triphasic burst occur is essential to understanding how the triphasic pattern serves to augment ballistic movement; Hallet and Marsden's study (1979) confirmed the initial findings of Wacholder and Altenberger (1926), indicating that at the end of the first agonist burst, it is typically seen that the beginning of the antagonist burst occurs, and that the end of that burst subsequently marks the beginning of the second agonist burst. Roy and Keller (1988) produced similar results, in that the antagonist burst occurs during the silent period between the first and second agonist burst. The duration of each component of the triphasic pattern may change depending on the circumstances under which the pattern is generated.

The combination of agonist and antagonist bursts of the triphasic pattern serve several purposes with respect to understanding how ballistic movement is controlled. Hannaford and Stark (1985) determined the first agonist burst served to initiate movement, the antagonist burst, acted as a braking force, and the second agonist burst serves to augment the first agonist and antagonist bursts. The authors further described the purpose of the second agonist burst as enabling the antagonist burst to be larger, and so to provide a greater braking force, without affecting the actual movement velocity. In turn, the first agonist burst can be larger and provide greater movement velocity, because there would be sufficient braking force to terminate it. Therefore the strategy of the second agonist burst is to provide "reverse programming" to the entire movement. Similarly, Cooke and Brown (1990) determined that the initial agonist (AG1) and antagonist (ANT1) bursts aided the acceleration of the movement, while deceleration was associated with the second agonist (AG2) and second antagonist (ANT2) burst. The pairing of the agonist and antagonist bursts therefore determines movement control. Specifically, the increase and decrease of acceleration is seen with the AG1/ANT1 burst pair, respectively, while the increase and decrease of deceleration is seen with the ANT2/AG2 burst pair, respectively. These findings are in accordance with those of Wierzbicka (1986), who concluded the purpose of the third burst in the triphasic pattern assisted in the braking forces of the antagonist muscle group. It was also found that during ballistic movements, the role of the agonist muscle was to determine the distance moved, and the role of the antagonist muscle was to decrease movement time. More recently, Agostino et al. (1992) demonstrated the first agonist burst (AG1) worked in conjunction with antagonist inhibition (AntI) to promote force in a desired direction of movement.

The size of the agonist bursts will depend on several factors. Peripheral feedback (Angel, 1975), the degree of stretch of the muscle prior to the onset of contraction (Hallet and Marsden, 1979), the speed at which the contraction occurs (Marsden et al.1983), and the movement amplitude (Hallet and Marsden, 1979; Marsden et al.1983), have been implicated in altering the agonist burst appearance. Early work by Hallet and Marsden (1979) showed several different findings regarding the triphasic pattern. They concluded that an increase in the pre-stretch of a muscle prior to the beginning of a ballistic contraction would cause a larger initial agonist burst, whereas a release of the tension would subsequently decrease the size of the first agonist burst. The duration of the first agonist and antagonist bursts were found to be approximately 50-90 ms long, irrespective of the mechanical conditions under which the muscle was placed. They also determined that the amount of EMG activity displayed by the first agonist burst increased as the distance moved increased. In agreement with these findings, Marsden et al. (1983) showed a linear relation between first agonist burst activity and movement velocity. Similar to Hallet and Marsden's 1979 study, the work of Brown and Cooke (1984) showed the duration of the initial agonist burst to be dependent on movement amplitude. For example, smaller movement amplitudes generated bursts of approximately 70ms long, while larger amplitude movements cause longer duration bursts, upwards of 140ms. The authors noted during larger movements (between 30-40°), two components were present in the initial agonist burst prior to the completion of peak velocity.

The antagonist burst in the triphasic pattern has been said to be independent of movement amplitude, as demonstrated by Hallet and Marsden (1979). In their study, both first agonist and antagonist bursts were similar in duration regardless of the size of movement. This finding was contradicted in a later study by Marsden and colleagues (1983). The size of the antagonist burst was indeed related to the velocity and magnitude of the movement; as magnitude and velocity increased, so did the size of the antagonist burst. A possible explanation for these differences is that in the earlier study, conditions of stretch were applied against the agonist muscle at random. As mentioned previously in this paper, agonist stretch caused an increase in agonist EMG activity, while a release in the stretch caused a decrease in agonist EMG (Hallet and Marsden, 1979). In the triphasic pattern, the initial agonist burst is implicated in the distance moved by the limb, while the purpose of the antagonist burst is to allow for a braking mechanism in ballistic movement and to reduce movement time (Wierzbicka, et al.1986). An increase in the stretch of the agonist muscle would potentially allow for more force production, due to the elastic properties of muscle, which would further relate to an increased need for braking forces to be present once the movement has been executed. This phenomenon may be present regardless of the angle through which the movement occurs.

The triphasic EMG pattern possesses both feed-forward (first agonist burst and initial portion of antagonist burst) and feedback (later portion of antagonist burst and second agonist burst) control (Angel, 1975), indicative of central and peripheral neural influence. Feed-forward control has been demonstrated by Hannaford and Stark (1981), in that movement amplitude was dependent on initial agonist burst size. Roy and Keller (1988) demonstrated the role of the antagonist burst in providing a braking force and controlling limb movement, which is indicative of feedback control.

While the triphasic burst contributes to the high rate of force development control of ballistic contraction, other neuromuscular considerations, such as motor unit recruitment and rate coding may enhance ballistic contractions.

B. Recruitment and Rate Coding in Ballistic Contractions

According to the size principle (Henneman et al.,1965a and 1965b), larger motor units posses a greater threshold of depolarization than smaller motor units, and small motoneurones have a lower firing threshold than larger ones. Essentially, motor units are recruited from small to large, which is proportional to the amount of force generated by the motor units.

It is well known that during ramped voluntary contractions, motor unit recruitment follows that of the size principle (Milner-Brown et al., 1973; Tanji and Kato, 1973). This has been demonstrated by Milner-Brown et al. (1973), who examined recruitment properties in the first dorsal interosseous muscle of the hand during voluntary isometric contractions. They showed that the increase in force threshold elicited an increase in the size of motor units recruited. This is consistent with work done by Henneman et al. (1965a and 1965b).

Desmedt and Godeaux (1977 and 1979) examined the recruitment properties during ballistic contractions in man over the course of two studies. In 1977 they examined discharge patterns of tibialis anterior muscles over several rates of force developments, during ramp and ballistic isometric contractions. During ramp contractions, motor units initially fired at approximately 5-15 Hz, and subsequently increased the firing rate as force increased. However, in strong ballistic contractions, motor units initially fired at 60-120 Hz and then decreased their firing rate. Overall, recruitment order was maintained in ballistic contractions; there were occasional exceptions during several instances, however, where a high-threshold motor unit fired before those under which less force was required to recruit them. Additionally, the amount of force required to recruit high-threshold motor units was less during ballistic contractions than during slower ramp contractions. In 1979 Desmedt and Godeaux compared recruitment and discharge patterns of several 'fast' and 'slow' muscles during ballistic and ramp contractions. The orderly recruitment of motor units was maintained in all muscles, and similar occurrences of recruitment threshold were seen during ballistic contractions.

C. Supraspinal Factors in Voluntary Ballistic Movement

While the cerebral cortex has a critical role in execution of movement, the actual process of movement involves several steps: i) the pre-motor and supplementary motor areas are involved in the anticipation of and in programming the movement, and in transferring the idea of movement into the actual execution; ii) the primary motor area will signal the muscles to produce a movement when stimulated (Sergio and Kalaska, 1998); iii) the cerebellum assists in control of the movement via coordinating limbs (Hulsmann, et al.2003); and, iv) spinal mechanisms provide feedback to central structures that further modify output if necessary (Cohen, 1953).

With respect to ballistic contractions, Mills and Kimiskidis (1996) showed that despite differences in EMG patterns, motor cortex activity was similar during ballistic movements of the muscles in the upper and lower arm, when the cortex was stimulated using transcranial magnetic and electrical stimulation. EMG of the biceps brachii and triceps brachii showed a traditional triphasic burst pattern during rapid elbow flexion, while rapid index finger abduction showed a single agonist burst in the first dorsal interosseous muscle. It was postulated that a similar central motor program was present for the completion of both movements, despite the differences seen in muscle activation. Desmedt and Godeaux (1979) indicated that the process within the motor cortex controlling ballistic movement is finalized before the movement is actually initiated. Therefore, once the person makes the decision to move quickly, it cannot be adjusted during the movement itself. This is largely due to the rapid nature of the contraction, which prohibits any feedback regarding the initial portion of the movement (Desmedt and Godeaux, 1979).

D. Spinal and Peripheral Factors Involved in Voluntary Ballistic Movement

Afferent control corrects motor output at the level of the spinal cord in order to provide the higher brain centres with time to integrate incoming information and determine the appropriate motor output. Angel et al.(1970) lend further evidence to spinal/supraspinal factors in voluntary movement control. They again observed unloading on agonist EMG, this time under a variety of unloading and blocking conditions, and found during unexpected unloading, a silent period was present in the agonist EMG. When a mechanical block was implemented after unloading, motor activity resumed, presumably by reactivation of muscle spindles (Angel et al.1970). Garland and Angel (1971) examined the role of spinal and supraspinal factors in controlling voluntary movement. The subjects contracted against various loads and EMG was recorded. When the load was removed during movement (active shortening of agonist), the second agonist burst was reduced, however when passive agonist shortening was induced, no change was seen in the initial agonist EMG burst. Garland and Angel (1971) proposed that because the initial agonist burst was not diminished in the unexpected unloading condition, peripheral factors did not contribute to EMG modulation. This is because a decreased amount of spindle activation would have caused a 'silent period' in the initial agonist EMG burst (Angel et al., 1965, in Angel et al., 1970). It can be seen above that proprioceptors play a key role in modulating voluntary movement, via activation of muscle spindles, and through the use of Golgi tendon organs. Early deactivation of muscle spindles can cause a diminished second agonist burst in EMG, which may be indicative of a lesser feedback response.

5. Conclusion

In summary, several points regarding training specificity and neural adaptations should be revisited. Training specificity is vital for success in a sport setting, with velocity-specificity being a key component. The neural adaptations involved in training- and velocity-specificity allow for improved performance via diminished inhibitory and increased excitatory stimulation. In high-velocity ballistic movements, a triphasic EMG pattern can be seen among agonist and antagonist muscles. The function of the bursts in the triphasic pattern is to augment the force being produced by the muscles, with the second agonist burst providing feedback to help mediate the initial agonist and antagonist bursts. This feedback mechanism is controlled by both peripheral factors within the musculo-tendon unit, and by reflex mechanisms within the spinal cord. The combination of these factors contributes to the usefulness of ballistic training in a sport setting.

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A Comparison of Ballistic Movement and Ballistic Intent Training on Muscle Strength and Activation

Nicole Dinn
School of Human Kinetics and Recreation
Memorial University of Newfoundland
St. John's Newfoundland, Canada

Running Title: Ballistic Training for Strength and Activation

ABSTRACT

Introduction: There remains a debate as to whether or not it is the intent to perform ballistic contractions that determines velocity-specific gains in training. Studies have both supported and refuted this concept. *Purpose*: The purpose of this investigation was to determine if ballistic intent is as effective as ballistic movement in improving muscle activation, force, movement time and reaction time. *Methods*: Subjects completed 8 weeks of punch training. The Dynamic (DYN) group trained with elastic resistance bands, while the Isometric (ISO) group trained with an unyielding strap. A Control (CTRL) group was also tested. Pre- and post-testing measures included isometric force, electromyography (EMG) of triceps, biceps, pectoralis major, and latissimus dorsi, movement and reaction time of both arms, and a Quick Hands test of coordination. *Pre- and Post-Training Measures*: Triceps iEMG increased by 63% in the ISO group. A six-fold decrease in time to onset difference was seen with the ISO group (collapsed across arms and trials) indicating a much smaller temporal separation of pectoralis major and latissimus dorsi activation. Pectoralis major iEMG increased by 65% in the DYN group. Movement time decreased 17.6% in the DYN training group. No other significant differences were found for other variables measured. *Conclusions*: Dynamic punch training improves movement speed and pectoralis major iEMG. Isometric punch training improves tricep iEMG but does not improve movement speed, and may impair bilateral arm movement coordination. Because of its specificity of movement, dynamic training may be a more appropriate method to improve punching speed and co-ordination for martial artists and boxers. The intent to contract explosively does not appear to be beneficial in increasing force production or speed of movement in punching.

Key words: punching, martial arts, force, co-contractions, electromyography

INTRODUCTION

Training that is specific to an athlete's sport is a vital component of any strength and conditioning program, and is advocated for many sports (DeRenne et al.,2001; Young et al., 2001). In considering sport-specific training, the velocity (Coyle et al., 1981) and movement (Young et al., 2001) should match as closely as possible the sport setting in order to achieve desirable results. Many sports typically involve high-velocity, explosive movements, and ballistic contractions (Zehr and Sale, 1994). Research on ballistic movements has both supported and refuted claims in the efficacy of their inclusion on sports training programs, in that both slow (Liow and Hopkins, 2003) and fast (Paddon-Jones et al., 2001) velocity training has been implicated in sport-specific improvement. Behm and Sale (1993) investigated the notion of attempted ballistic training and reported that it was the *intent* to contract explosively, and not the actual movement itself, that is a key factor in improving peak torque and rate of torque development in the lower leg muscles. A more recent study by Olsen and Hopkins (2003) using a ballistic intent to contract, found subjects who trained using conventional and isometric ballistic kick training increased their speed, but decreased the amount of force produced.

The purpose of the present study is to determine whether it is the intent to contract at a high velocity (using isometric training) or the actual movement speed (using dynamic training) that determines the greatest gains in strength, reaction and movement time, as well as other velocity-related performance measures. Changes in electromyographic (EMG) activity and co-ordination will also be examined in attempt to understand possible mechanisms. To remove possible confounding effects of cross-education, subjects will train with a single arm. Additionally a control group is implemented in the study design to examine the overall effects of the training program.

METHODOLOGY

1. Subjects

Twenty subjects participated in this study. Subjects were recreationally active, participating in either resistance training or martial arts between three and six days per week, but not competitive in their chosen activity (Table 1). Subjects were recruited from the University population and greater St. John's area. All subjects read and completed an Informed Consent form, and were given the opportunity to ask questions of the researcher regarding the study. All subjects were free of injury. Approval for this study was granted through the Human Investigation Committee, Memorial University of Newfoundland.

	Age (years)	Height (cm)	Weight (kg)	Recreationally Active	Martial Artists
Control (n=6)	21.3±1.6	177.5±10.7	82.7±29.9	6	0
Dynamic (n=7)	28.1±9.7	168.9±5.2	67.5±11.6	4	3
Isometric (n=7)	22.1±2	170.3±6.3	80.5±20.1	5	2

Table 1: Subject characteristics.

2. Testing Protocol

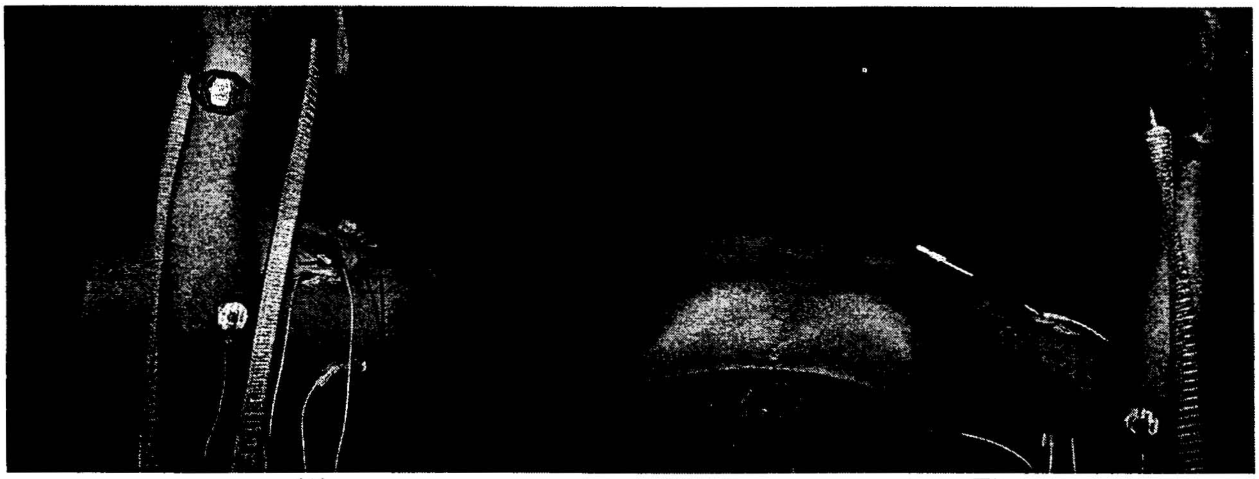
Subjects underwent two bouts of testing before and two bouts of testing after an eight-week training program. Each testing bout was separated by one week. The initial testing bout consisted of measuring electromyography (EMG), force, movement and reaction time, and the Quick Hands Test. The second bout consisted of EMG and force. EMG and force measures were taken twice to establish intraclass reliability coefficients, removing the need for normalizing EMG data against maximal voluntary contractions (MVCs). The subjects then began their training program immediately after the second testing bout. Following the completion of the training program, subjects immediately began the post-training testing. The tests completed in the initial testing bout were repeated. The second testing bout occurred one week after training ceased and consisted of EMG, and force, (See Figure 1 below).

Figure 1: Schematic of testing and training protocol.

Testing consisted of the following:

A. Maximal Voluntary Contractions (MVC):

The subject was laid supine on a table, with straps placed slightly below the knee and above the hip to restrict movement. The subject held a handle which was fixed to a strain gauge (Wheatstone bridge configuration, Omega Engineering Inc., LCCA 250, Don Mills, ON) with the arm held at 45° abduction from the body, and the elbow bent at a 90° angle. The length of the handle restricted the subject to a 90° angle at the elbow. The subject was instructed to hold one side of the table with the hand that was not being tested, and was also instructed to keep this position throughout testing (Figures 2A and 2B). On instruction from the researcher, the subject attempted to perform a maximal voluntary contraction (MVC) in the form of a punch, by executing an elbow extension movement. The MVC was held for 1.5-2 seconds.

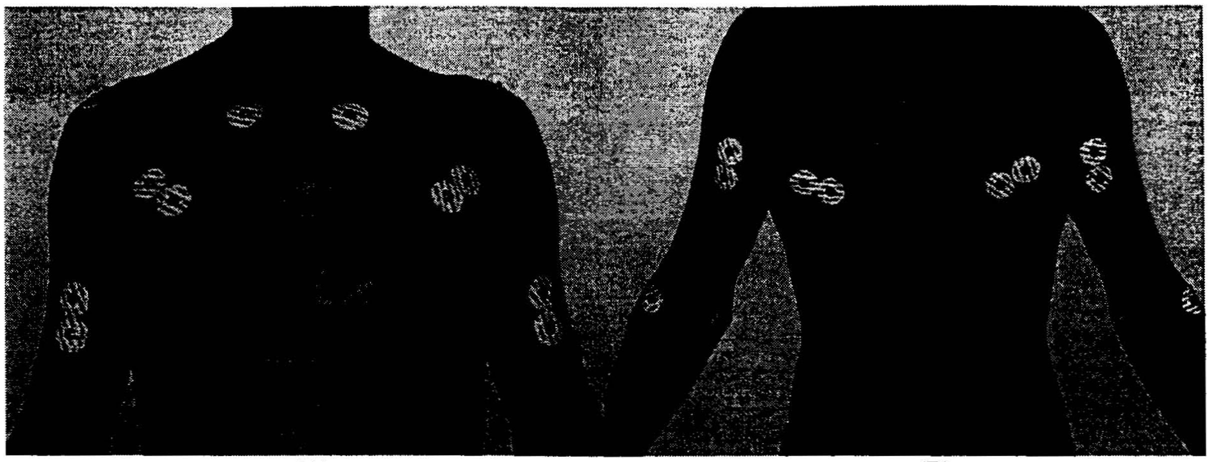


(A) (B)

Figures 2A and 2B: Position of subject in preparation for Force/EMG data collection.

B. Electromyography (EMG):

Electrodes (MediTrace, Kendall ©, 1cm silver/silver chloride recording area, 3cm inter-electrode distance) were placed on the muscle belly of the following muscle groups: midway between the acromion and olecranon processes on both the biceps brachii and triceps brachii; midway between the axilla and thelium on the pectoralis major; approximately 1-2cm below the inferior angle of the scapula and midway from the inferior angle of the scapula to the axilla, on the latissimus dorsi (Figures 3A and 3B). All electrodes were placed in line with the direction of fibers of the corresponding muscle. EMG activity was sampled at 2000Hz, filtered with a Blackman -61 dB band-pass filter (10-500Hz), amplified [bi-polar differential amplifier, input impedance = 2M Ω, common mode rejection ratio >110 dB min (50/60Hz), gain x 1000, noise >5μV], and analog-to-digitally converted (12 bit).



(A) (B)

Figures 3A and 3B: Placement of the electrodes on the pectoralis major and biceps brachii (2A) and on the latissimus dorsi and triceps brachii (2B).

C. Quick Hands test:

The subject faced a contact mat, which was fixed to a wall at approximately shoulder height. The subject stood with arms fully extended, palms against the mat. They were then instructed to step forward and keep their hands on the mat so that the elbows were bent to approximately 70° (Figures 4A and 4B). The subject reacted following a verbal command ("Go") from the researcher. The subject was instructed to hit the mat with the palms of their hands as many times as possible for ten seconds. No encouragement was given from the researcher. The subject stopped when she or he heard the "Stop" command from the researcher (Dintiman and Ward, p. 21, 2003) The number of contacts made within a ten second period, and the average number of contacts made in one second, were calculated. Data were collected using the Innervations © Kinematic Measurement System, v. 2004.2.0. Data was collected on a computer (Sona Computers, St. John's NL; Pentium 4 2.8GHz processor, 512 MB RAM).

(A) **(B)**

Figures 4A and 4B: Apparatus configuration and subject orientation for Quick Hands test.

D. Movement and Reaction Time:

The movement-reaction time apparatus was developed by Memorial University Technical Services (Newfoundland, Canada) and consisted of: a stop clock (58007, Lafayette Instrument Company, Lafayette, IN) and analog timer (L15-365/099, Triton Electronics, Great Britain); an incandescent light; a trigger plate; and a subject-activated movement-reaction time initiator. This final component consisted of a custom designed box (62 cm X 15.5 cm X 9 cm), with a start button and stop button positioned 50cm apart. The subject was seated such that the initiator apparatus was placed laterally to their body. The height of the chair was adjusted so when the subject sat and placed their hand on the button, elbow flexion was approximately 90° (Figure 5 below). The subject held down the blue button so that the distal end of the metacarpals touched. When the researcher activated the switch for the light, the subject was instructed to hit the red button as fast as possible. Turning on the light started both the movement and reaction time clocks. Reaction time was taken as the time between the flash of the light and the release of the blue button. Movement time was taken as the time between the release of the blue button to when the red button was compressed.

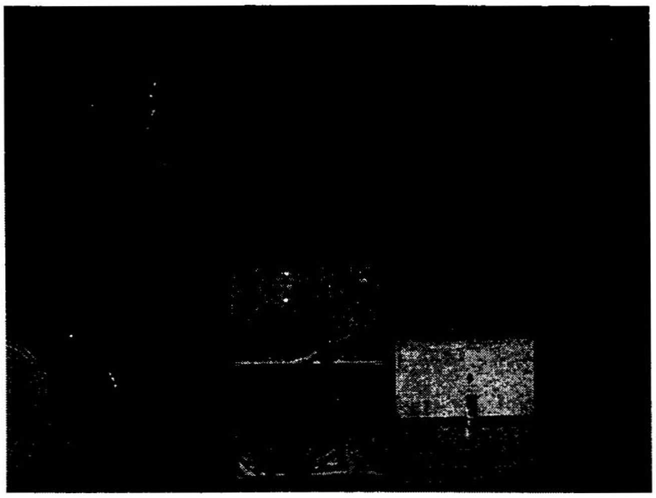
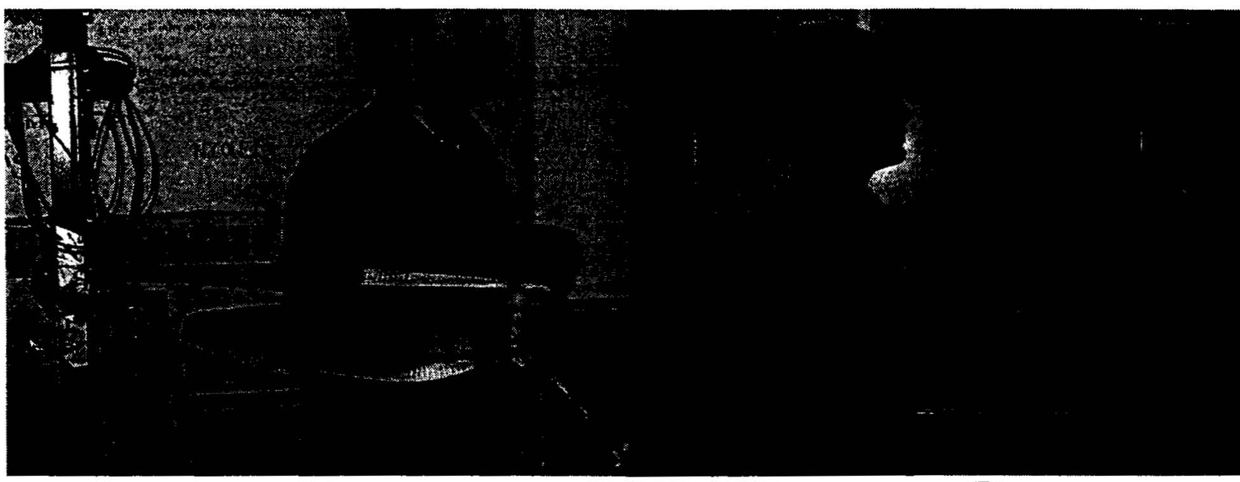


Figure 5: Movement-Reaction time apparatus.

3. Training Program

Each subject participated in an eight-week training program, with a training frequency of three days per week. Subjects were divided into an Isometric training group (ISO), Dynamic training group (DYN) or control. In the DYN group, sessions consisted of using an elastic band to train the arm for hand punching. Subjects in the ISO group performed punching movements against an immovable object using heavy cording fixed to a handle (Figures 6A and 6B). In weeks one and two, subjects performed three and four sets, respectively, of ten repetitions. In weeks five through eight, subjects performed five sets of ten repetitions. Subjects rested between 45 and 60 seconds between sets. Each session length was approximately 10 minutes long. The goal of the program was to progressively increase the amount of resistance used (for the DYN group) or the effort exerted (for the ISO group) during punching. The initial amount of elastic resistance used was determined by a trial and error method. The subject was given a series of elastic bands that progressively increased in resistance with which to practice the punch movement. When the subject could barely extend their arm fully, this was determined to be the starting resistance used. The subject was then instructed to continue adding elastic bands as necessary to ensure sufficient overload was maintained throughout the training program. Training was monitored on a regular basis by the primary investigator. Subjects participating in the ISO group were instructed to continually increase the effort used when punching throughout the training program.



(A) **(B)**

Figures 6A and 6B: Apparatus for dynamic (6A) and isometric (6B) training.

The elastic bands used for the training program varied in tension, from 3.18 kg (7 lbs) to 11.5 kg (25.3 lbs) at 250% elongation (Thera-Band Systems Inc. 2006; see Table 2). Subjects used either a single or a combination of resistance bands for their training program.

Medium	3.18kg (7lbs)
Heavy	4.36kg (9.6lbs)
Extra Heavy	6.04kg (13.3lbs)
Special Heavy	8.0kg (17.6lbs)
Super Heavy	11.5 kg (25.3lbs)

Table 2: Maximum Strength of Elastic Bands in kg (lbs in parenthesis) – Theraband © (at 250% elongation)

Because the act of hand punching works primarily the triceps brachii, pectoralis major and deltoid muscles, a potential for creating imbalances between anterior and posterior muscles exists. To correct this, subjects performed pulling movements. This ensured that muscles that assist in flexion/pulling (latissimus dorsi, trapezius, and biceps brachii) are trained. The training variables (sets, repetitions, resistance and speed) were the same as that for the hand punching movement.

4. Data Analysis

A. Electromyography:

EMG activity was full-wave rectified and filtered over 200ms at and prior to the peak of the force. All data for EMG were collected on a computer (Sona Computers, St. John's NL; Pentium 4 2.8GHz processor, 512 MB RAM).

B. Time to EMG Onset Difference:

The time to EMG onset commenced when the mean baseline EMG values calculated over a 200 ms duration were exceeded by two standard deviations (SD). When the EMG recording obtained this value (baseline mean +2SD) for longer than 50ms, the contraction was considered to be initiated.

5. Statistical Analysis

The study was a between group, repeated-measures design. Subject data were examined pre- and post-training, and the data were compared against a control group. Statistical analysis was performed using SPSS (v. 12.0). A 3-way ANOVA was implemented on EMG and force (arm x trial x pre-post). Two-way ANOVAs were conducted on movement and reaction time (arm x pre-post). A one-way ANOVA was conducted on the Quick Hands test (pre-post). Significance was present if $p<0.05$. Bonferroni's Post-hoc test was conducted if significant results were present after the ANOVA. Intraclass correlation coefficients (Cohen, 1988) were performed on force and each muscle group EMG between the first and second testing sessions pre-training. This was performed to establish reliability in testing methods. Data in the text and figures includes means ± SD. To reduce the variability in the force and EMG measures, the researcher took great care in ensuring electrode placement was accurate across multiple testing sessions (via anatomical landmarking and using anthropomorphic measures). Levene's Test of Homogeneity was performed on force and EMG, to ensure reliability in EMG electrode placement. Significance was present if $p<0.05$.

RESULTS

1. Measures of Reliability

A. Intraclass Correlations (ICCs). Intraclass correlations were moderate to strong (Daniel, 2005) on force and all integrated electromyography (iEMG) recordings (Table 3).

Isometric Force	0.947
Triceps Brachii iEMG	0.752
Biceps Brachii iEMG	0.881
Pectoralis Major iEMG	0.647
Latissimus Dorsi iEMG	0.587

Table 3: ICCs between Trial 1 and 2, pre-training for all muscle groups.

B. Test of Homogeneity. Levene's Test of Homogeneity was performed on force and EMG measures (Table 4). Significance was present if $p<0.05$. Significant findings were found in the control (CTRL) group for the biceps brachii, and in the isometric (ISO) and dynamic (DYN) training groups for the latissimus dorsi. These variances can be accounted by the small sample size of each group in the study, and corresponding variability in the data.

	Isometric Force	Triceps Brachii	Biceps Brachii	Pectoralis Major	Latissimus Dorsi
Control	0.987	0.395	0.007	0.077	0.605
Isometric	0.727	0.067	0.364	0.278	0.048
Dynamic	0.836	0.370	0.424	0.741	<0.001

Table 4: Levene's Test of Homogeneity p-values.

2. Force Production

No significant differences in force production were seen between groups, across trials, or between pre- and post-training measures.

3. Electromyography (EMG)

A. Triceps brachii. A significant ($p=0.03$) increase of 63% was observed for triceps brachii iEMG with the isometric (ISO) training group between pre- and post-training measures (collapsed across arms and trials) (See Figure 7). No significant differences were seen in either the CTRL (p=0.45) or DYN (p=0.60) groups.

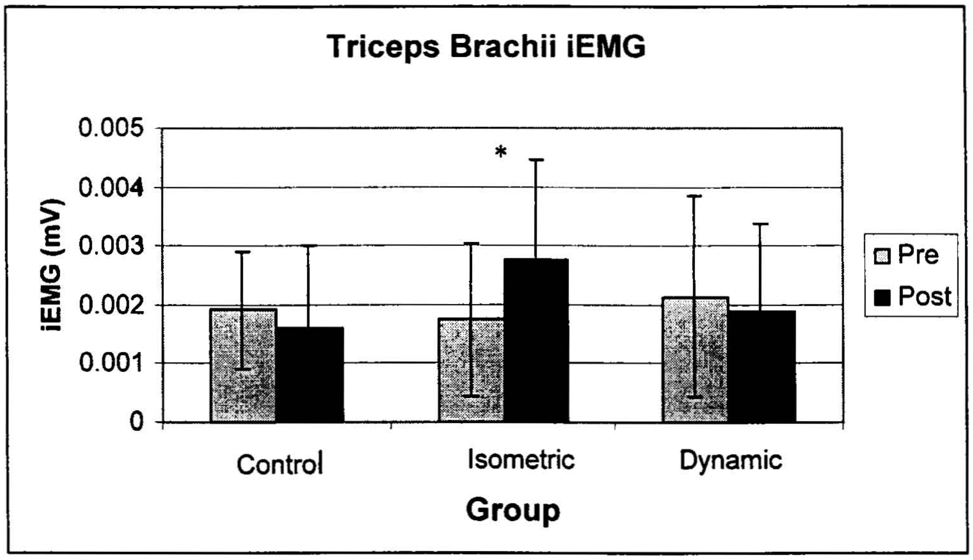


Figure 7: iEMG of the Triceps brachii muscle group. Significance is denoted by an asterisk (*). Columns and bars represent means and standard deviations, respectively.

B. Biceps brachii. A tendency for an increase of 26% of the biceps brachii iEMG was found in the DYN group between pre- and post-training measures, however this was not significant (p=0.08) (See Figure 8).

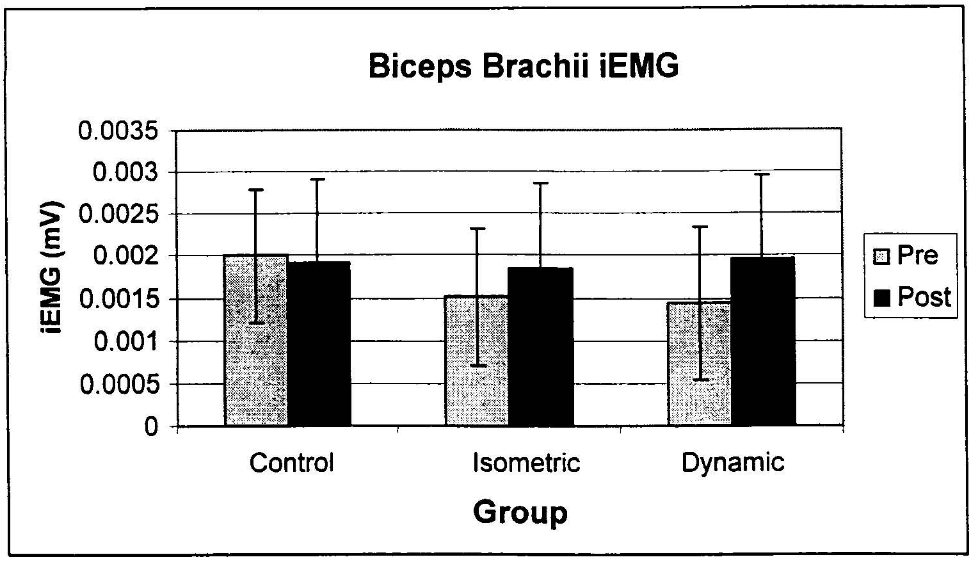


Figure 8: iEMG of the biceps brachii muscle. Significance is denoted by an asterisk (*). Columns and bars represent means and standard deviations, respectively.

<u>C. Pectoralis Major.</u> A significant (p=0.007) increase of 65% with pectoralis major iEMG was seen in the DYN group post-training (collapsed across both arms and trials) (See Figure 9).

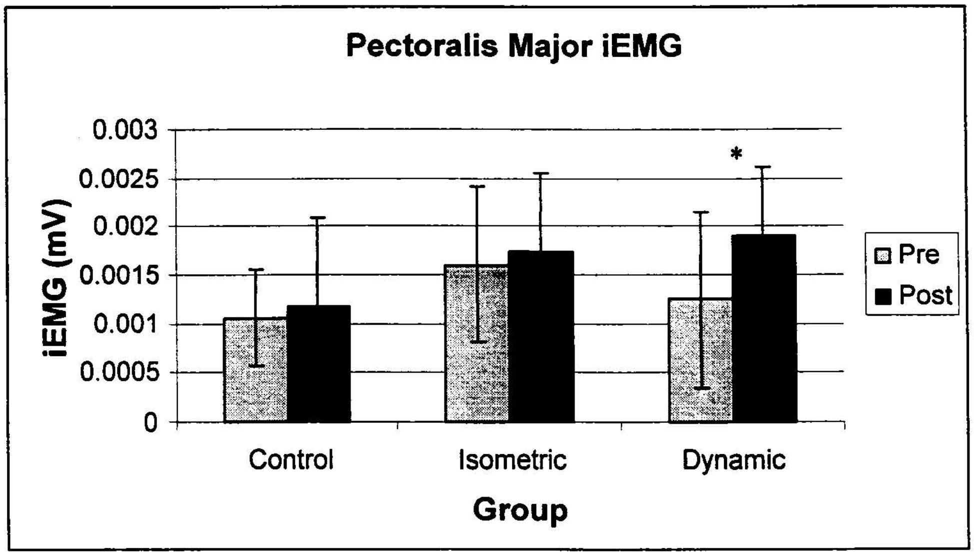


Figure 9: iEMG of the Pectoralis Major muscle group. Significance is denoted by an asterisk (*). Columns and bars represent means and standard deviations, respectively.

D. Latissimus Dorsi. No significant differences were found in the latissimus iEMG between trials, groups or pre- and post-training.

E. Time to Onset Difference. Because of the varying times in which the command to contract was given, the differences between agonist-antagonist muscle groups, and between agonist muscle groups was taken. With agonist-antagonist pairs, a positive number indicated the agonist muscle was activated first, while a negative number indicated the antagonist muscle was activated first. With agonist-agonist pairs, a smaller number would indicate the ability of each muscle to fire more synchronously.

i. Triceps brachii – Biceps brachii. There were no significant differences in triceps brachii – biceps brachii temporal activation patterns. The biceps brachii muscle was activated before the triceps brachii muscle across all variables measured.

ii. Pectoralis Major – Latissimus Dorsi. A significant ($p=0.03$) decrease by six-fold in time to onset difference was seen with the ISO group between pre- and post-training measures (collapsed across arms and trials) indicating a much smaller temporal separation of pectoralis major (agonist first) and latissimus dorsi (antagonist second) activation (See Figure 10).

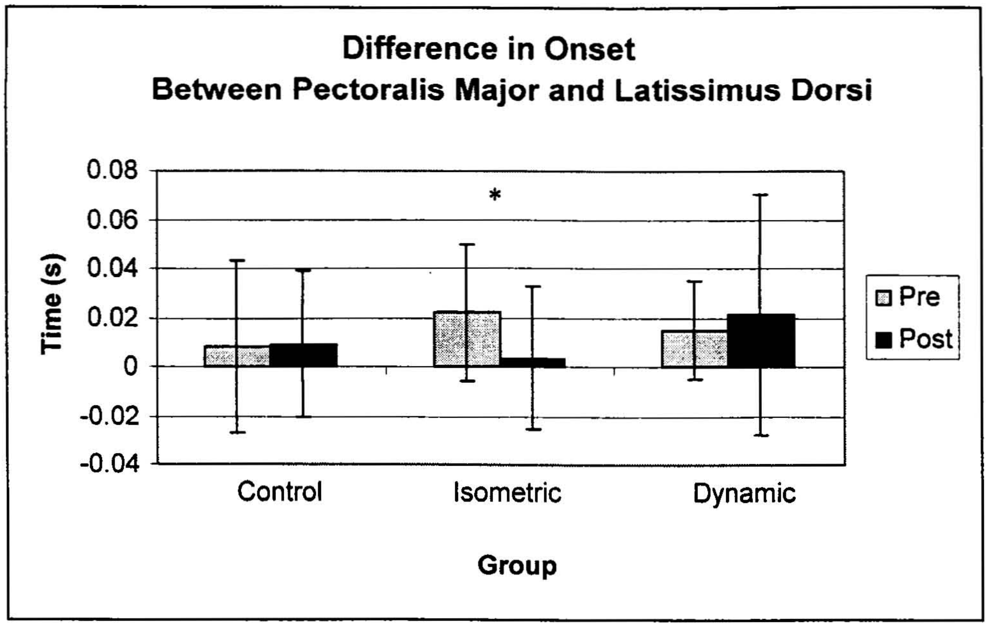


Figure 10: Time to onset difference between pectorals (agonist) and latissimus (antagonist) muscle groups. Significance is denoted by (*).Columns and bars represent means and standard deviations, respectively.

iii. Triceps brachii – Pectoralis Major. Significant decreases in time to onset difference were seen in the ISO ($p=0.03$) and CTRL ($p<0.001$) groups between pre- and post-training measures (collapsed across arms and trials), indicating the pectoralis major was activated before the triceps brachii. The difference in time between onset of the triceps brachii and pectorals decreased 82.6% post-training in the CTRL group, and decreased 85.1% post-training in the ISO group (See Figure 11). No significant differences were found in the DYN group.

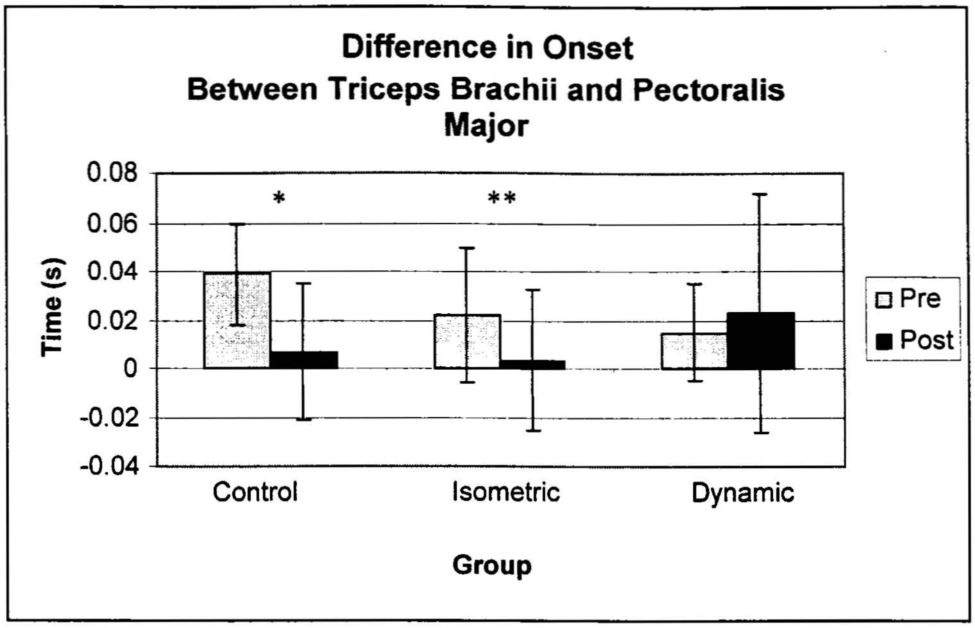


Figure 11: Time to onset difference between triceps brachii and pectorals muscle groups. Significance in CTRL group is denoted by a single asterisk (*) (p=0.00), and by a double asterisk (**) in ISO group (p=0.036).

4. Movement and Reaction Time

<u>A. Movement Time.</u> A significant 17.6% decrease (p=0.001) in movement time was seen in the DYN training group between pre- and post-training measures (collapsed across both arms) (See Figure 12). No significant differences in either the CTRL or ISO groups were seen.

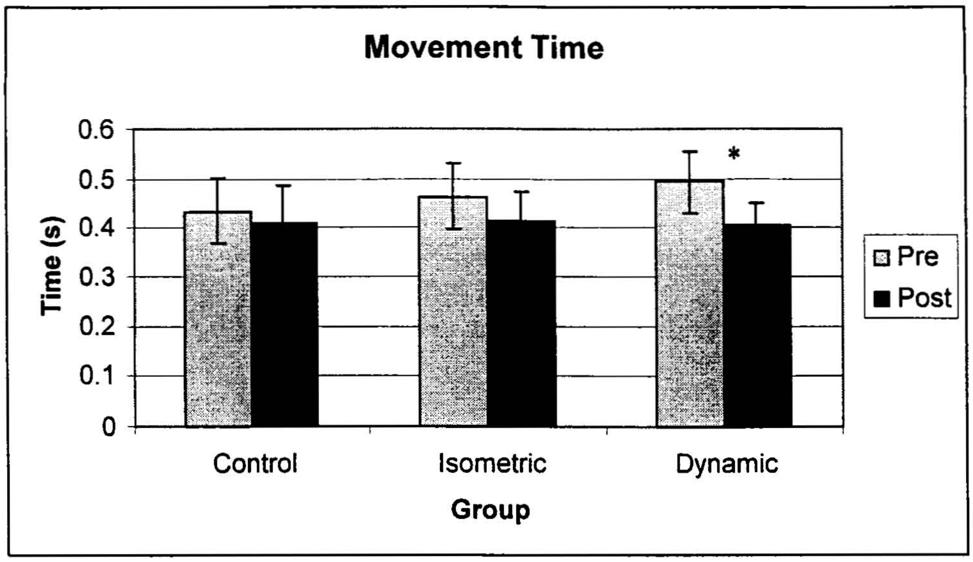


Figure 12: Movement time pre- and post-training. Significance is denoted by *. Columns and bars represent means and standard deviations, respectively.

<u>B. Reaction Time.</u> There were no significant differences in reaction time for any variable or group.

5. Quick Hands Test

<u>A. Contacts per Second.</u> No significant differences were seen in the number of contacts made per second between groups or pre- and post-training measures.

<u>B. Number of Contacts.</u> A tendency was seen for decrease by 16.8% in the total number of contacts per trial in the ISO group post-training, however this was not significant ($p=0.07$) (See Figure 13).

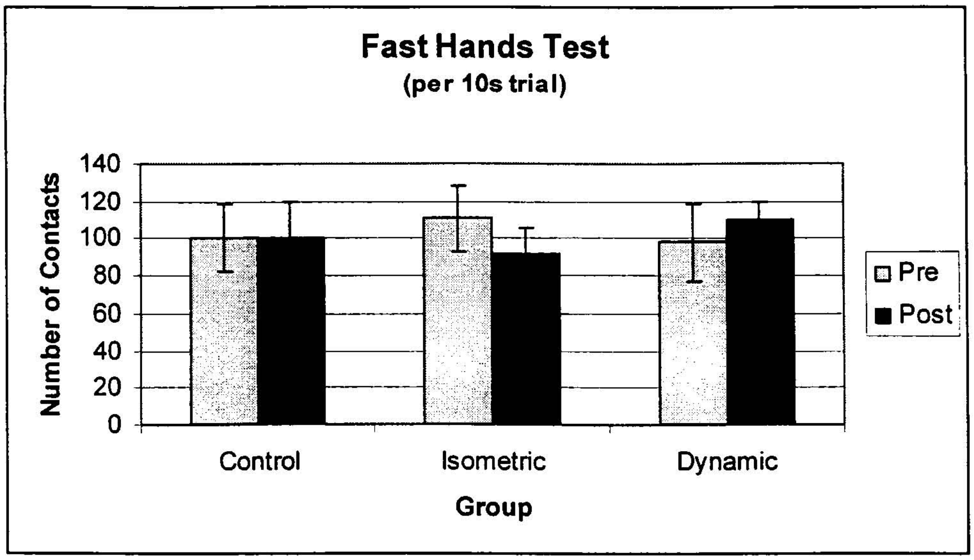


Figure 13: Number of contacts per 10 second trial. Columns and bars represent means and standard deviations, respectively.

DISCUSSION

The most important findings of the study were the changes in movement speed with training. Dynamic training improved basic movement speed whereas there was a tendency for a decrease in the rate of coordinated movement following isometric training. There were also training-specific changes in iEMG activity and muscle activation patterns.

1. Force Production

No changes in force production were seen between any groups tested. Previous studies have demonstrated significant increases in strength (Farthing and Chilibeck, 2003; Paddon-Jones et al., 2001), hypertrophy (Farthing and Chilibeck, 2003; Shepstone et al.2005) and iEMG (Hakkinen et al.2001) with high velocity or explosive contraction training. However, Olsen and Hopkins (2003) found a decrease in force in subjects who trained with ballistic intent and conventional weight training to improve punching and kicking. Conversely, Behm and Sale (1993) also used ballistic intent training and found an increase in peak torque of dorsiflexors post-training. The differences in results may be explained by the fact that both kicking and punching are complex, multi-joint movements which require coordination and balance. However, dorsiflexion is a single-joint movement. Olsen and Hopkins argued that force might have been decreased because subjects concentrated on maintaining balance, control and correct technique while attempting to kick. Furthermore, they noted that less-skilled subjects (in martial arts) demonstrated decreases in force that were greater than those subjects who were more skilled. A similar argument could be made for the present study in that nine of the 14 training group subjects were untrained in boxing or martial arts, and thus would not have developed the coordination skills necessary to execute punches properly. While the researcher ensured a standard punching method across all subjects, the goal of the study was not to teach subjects to develop specific punch technique.

Time-under-tension may be a factor involved in strength gains or fiber hypertrophy with resistance training. Gilles et al. (2006) demonstrated greater increases in Type I and IIA muscle fibers with training using concentric contractions lasting six seconds than with concentric contractions lasting two seconds. Additionally, leg press strength was greater when training involved six-second eccentric muscle actions (contractions) than when two-second eccentric muscle actions (contractions) were employed. Liow and Hopkins (2003) demonstrated that slower resistance training as opposed to ballistic movements were more effective, as seen in improvements during the acceleration phase of a sprint in kayaking. In the present study, contractions during training and testing were brief (lasting 1.5 – 2 seconds) and thus enough time-under-tension may not have been provided to elicit strength gains. Kanehisa and Miyashita (1983) examined the effects of isokinetic and isometric training on static strength and dynamic power. Similar to the dynamic group in the present study, no changes in isometric strength were seen after the dynamic training. McBride and colleagues (McBride et al., 2002) examined the effects of heavy- and light-load jump squats on various speed, strength and power tests. Improvements in velocity-related components were seen in the light-load group, while the high-load group showed improvements in strength- and power-related components. In the same context, the high contraction speeds in the present study did not provide isometric strength gains but did ameliorate movement speed.

One limitation of the present study was that there was minimal external feedback regarding force or effort during training. When one performs resistance training with machines or free weights, the amount of weight lifted or force exerted can be seen and tracked; in the case of strain gauges, the force exerted can be illustrated. Although subjects were supervised during training, they may not have been motivated during all training sessions to exert maximally against the isometric cord or elastic resistance during training, which may have affected results.

2. Electromyography

Triceps brachii iEMG increased significantly by 63% post-training in the ISO group, but not in the DYN group. The lack of increase in triceps brachii iEMG in the DYN group may be due to the position of the pectoralis major during the punch action in the present study. In the ISO training, the pectoralis major is placed in a lengthened position. The force-length relationship of the pectoralis major in this position would result in poor force-production capabilities (Gordon et al., 1966, reported in Sandercook and Heckman, 2001). Since muscle tension is one of the major factors contributing to the training-induced stress necessary for strength (Alegre et al., 2006) and activation adaptations (Suetta et al., 2004) the reduced force output of the pectoralis major during ISO training would have minimized iEMG changes. The minimal pectoralis major force contribution would result in a greater contribution from and increased tensile stress on the triceps brachii muscle.

Conversely, pectoralis major iEMG increased significantly post-training by 65% in the DYN group but not the ISO group. The pectoralis major experienced a wide range of motion during DYN training, and when considering both the length-tension and force-velocity relationships, this would lead to greater force-production capabilities at the more optimal joint angles. With the pectoralis major providing a greater contribution, and perhaps a higher degree of momentum during training, the triceps brachii activation would have contributed less to movement in the DYN group than in the ISO group.

The biceps brachii iEMG demonstrated a tendency to increase in the DYN group post-training, although this was not significant. However, its role in shoulder stability and punching actions should not be ignored. Increases in biceps brachii EMG can be seen when the shoulder is in an unstable environment (Kim et al., 2001). Here, the biceps brachii participates in a compensatory role in attempting to correct instability, which is not seen in a stable shoulder joint. The punch action executed by the DYN group can be considered unstable due to the multiple planes of movement allowed with the elastic tubing. Thus, increased instability in the shoulder joint, combined with increased agonist (pectoralis major) forces on the joint, may explain the increased iEMG of the biceps brachii with the DYN group and not the ISO group.

Smaller temporal separation was seen among the pectoralis major/latissimus dorsi pair between pre- and post-training measures in the ISO group. In other words, the difference in time to onset between the pectoralis major and latissimus dorsi decreased post-training, and the activation of the pectoralis major and latissimus dorsi was more synchronous. A joint – protective mechanism may be in place during the punch action in the ISO group. Normally, one would expect greater temporal separation between the pectoralis major and latissimus dorsi in the punch action. However, in the isometric testing and training the shoulder joint was off the table, and thus in an unstable position. Typically in unstable environments, antagonist co-contractions are present to provide stability (van Dieen et al., 2003) and thus would help explain the more simultaneous activation of the latissimus dorsi with the pectoralis major. Furthermore, ballistic contractions tend to produce higher levels of antagonist co-activation (Sale, 1988). The small temporal separation between the pectoralis major and latissimus dorsi with ballistic-intent contractions in the present study may reflect this antagonist co-activation in the ISO group.

Greater activity of the antagonists may have contributed to the lack of training-related isometric strength gains.

No differences in temporal separation were seen among the triceps brachii/biceps brachii pair between pre- and post training among any of the groups. However, the biceps brachii muscle was activated before the triceps brachii muscle in all groups tested. With the shoulder positioned off the table during testing, the biceps may have activated prior to the triceps to ensure stability of the shoulder. Hodges and colleagues (1997) have reported on anticipatory postural adjustments of trunk muscles prior to upper limb movement. In their study, trunk muscles such as the multifidus and transverses abdominus were activated prior to the intended movement of the shoulder in order to anticipate a disruptive torque and thus protect the trunk. In the present study, the biceps brachii may also have anticipated the intended contraction of the shoulder and provided a stabilizing force.

Temporal separation between the triceps brachii and pectoralis major group decreased post-training in the ISO and CTRL groups, meaning the triceps brachii and pectoralis major were more synchronous after training. This may be due to a learning effect in the CTRL and the ISO groups, reflecting a tendency to use the triceps brachii more than the pectoralis major during the punch action.

3. Movement Time and Quick Hands Test

A significant decrease in movement time was seen in the DYN group post-training but not the ISO group. This may be due to training specificity, as the apparatus used to measure movement time more closely reflected the action used by the DYN group than the ISO group. Duchateau and Hainaut (1984) found dynamic training to cause an increase in maximal shortening velocity of the adductor pollicis when subjects trained with fast contractions (<0.5s). The intent to contract explosively does not appear to be a factor leading to improvements in movement speed, as no differences were seen in the ISO group. While previous studies (Behm and Sale, 1993; Olsen and Hopkins, 2003) demonstrated increased rate of torque development and increased movement speed, respectively, with intended ballistic training, the present study does not support these results. The training program elicited by Behm and Sale (1993) was 16 weeks, and Olsen and Hopkins (2003) had subjects train for ten weeks. Conversely, the length of the present study's program was only eight weeks, and a longer training program may produce more stable results in the ISO group.

A second mechanism providing insight to increases in movement speed in the DYN group could be the role of the biceps brachii as an antagonist muscle. Jaric et al., (1995) argued that while a strong agonist is responsible for acceleration of limb movement, the antagonist muscle is responsible for halting that movement, which would allow the acceleration phase to be longer.

The ISO group had a tendency to decrease the number of total contacts per trial in the Quick Hands test post-training. This may reflect movement speed, coordination and training specificity. In ballistic movements, antagonist coactivation is present and may serve to trigger a stretch-shortening cycle (Sale, 1988). In the present study, because of its explosive nature, the Quick Hands test may have also triggered a stretch-shortening cycle. While this test requires cyclical flexion and extension of the elbow, the agonist muscle would be the triceps brachii as its purpose is to extend the arm, allowing the hands to strike the contact mat. Here the biceps brachii serve as the antagonist muscle and its role in performance of the Quick Hands test would be to retract the arm away from the contact mat. As mentioned previously, antagonist strength is important in allowing a limb to accelerate (Jaric et al., 1995). Perhaps the lack of improved activation in the biceps brachii may have contributed to decreased coordination in the ISO group. The Quick Hands test involved rapid extension and flexion of the elbow joint, and in terms of training specificity this was more similar to the DYN training than the ISO training. Also, the DYN training may have enabled better proprioception within the upper body muscles, which would contribute to movement speed and coordination (Messier et al., 2003). Since the goal of the Quick Hands test was to perform as many contacts as possible in a ten second period, increased movement speed would be an advantage here. There were no improvements in movement time in the ISO group.

4. Limitations

A significant limitation to the study was the apparatus used to orient subjects for force and EMG data collection. Subjects were tested in a horizontal position, yet trained in a vertical position. The reason for horizontal testing was due to the configuration of equipment in the lab setting, which was beyond the control of the researcher. Had the testing apparatus been vertical, it would have more closely matched the training environment and perhaps significant results in force production may have been seen post-training.

Another limitation to the study could have been subject variability in training. Subjects who were already participating in resistance training or other physical activity program were permitted to complete the study, and were told they could maintain participation providing they did not significantly alter their current program or begin a new form of training. However, subjects were not monitored during their own training sessions, and any dramatic changes made to their training may have confounded study results. Furthermore, the addition of the present training program in conjunction with the some of the participants established programs could have resulted in an overtraining effect.

Anthropometric measures, such as height and weight, were taken before the study began, however neither body fat nor arm circumference were measured. Alterations in body fat content (Nordander et al., 2003) and muscle fiber diameter (De Luca, 1997) may impact EMG readings. Whether or not changes in these factors occurred with the present study is not known.

A final limitation is that most subjects were untrained in boxing or martial arts. Because of the level of skill required to properly execute punching movements, more time may have been spent on "getting the movement right" as opposed to executing punches with maximum effort. Olsen and Hopkins (2003) found less-skilled martial artists decreased force output more after training than those with more skill, likely owing to deficits in coordination and balance among those with less training. Future studies may want to implement a familiarization period to allow non-trained subjects to become accustomed with executing proper punch technique.

Correction of the above-named limitations in equipment setup and data acquisition/analysis methods may allow for more pronounced training affects. Additionally, having standardized subject characteristics (i.e. all martial artists or none) may improve findings.

5. Conclusion

Dynamic punch training improves movement speed and pectoralis major iEMG. Isometric punch training improves triceps brachii iEMG but does not improve movement speed, and may impair bilateral arm movement coordination. Because of its specificity of movement and because of the above results, dynamic training may be a more appropriate method to improve punch ability for martial artists and boxers.

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THESIS SUMMARY AND CONCLUSIONS

Training specificity, which includes exercises designed to improve a particular function or movement in a sport situation, is recommended for many sports. Components of training-specificity include movement, velocity, and range of motion specificity. The neural adaptations that occur with training include changes in recruitment and rate coding, antagonist co-contractions, and cross-education. These adaptations help to facilitate improvements in strength and muscle activation. The present study included the use of velocity-specific training and the intent to contract explosively to improve punch training. Main findings included a decrease in movement time with dynamic training, and impaired coordination with isometric training. Neural adaptations, demonstrated by changes in EMG, were also found. Because of its specificity of movement, dynamic training may be a more appropriate method to improve punching speed and co-ordination for martial artists.

APPENDICES

APPENDIX A – NON-SIGNIFICANT DATA

The following data were omitted from the original thesis content due to their lack of significance. However it is included in this section for archival purposes and to add to the continuity of the thesis.

1. Isometric Force

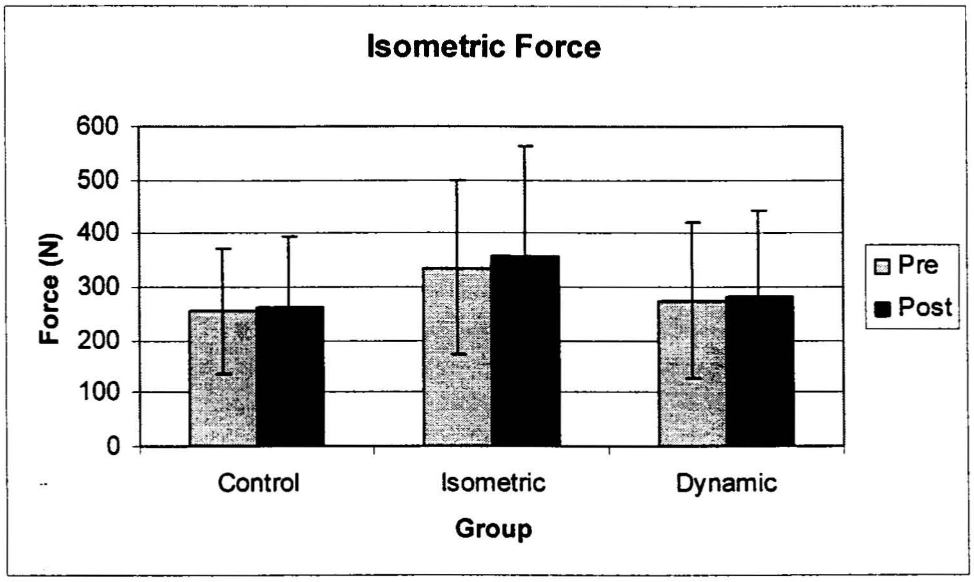

Figure I: Isometric Force, pre- and post-training. Columns and bars represent means and standard deviations, respectively.

2. Latissimus Dorsi iEMG

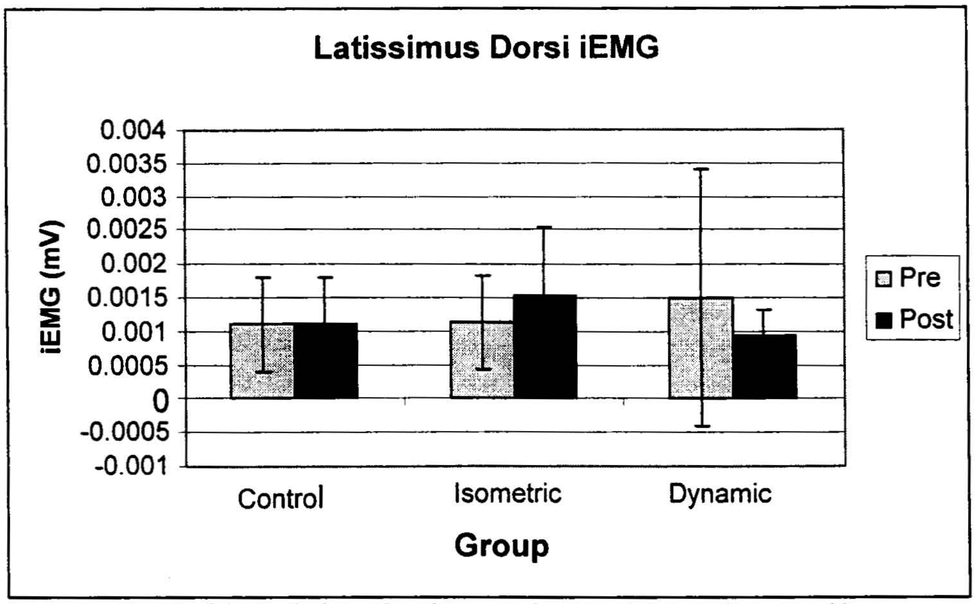

Figure II: iEMG of the Latissimus Dorsi, pre- and post-training. Columns and bars represent means and standard deviations, respectively.

3. Time to Onset Difference

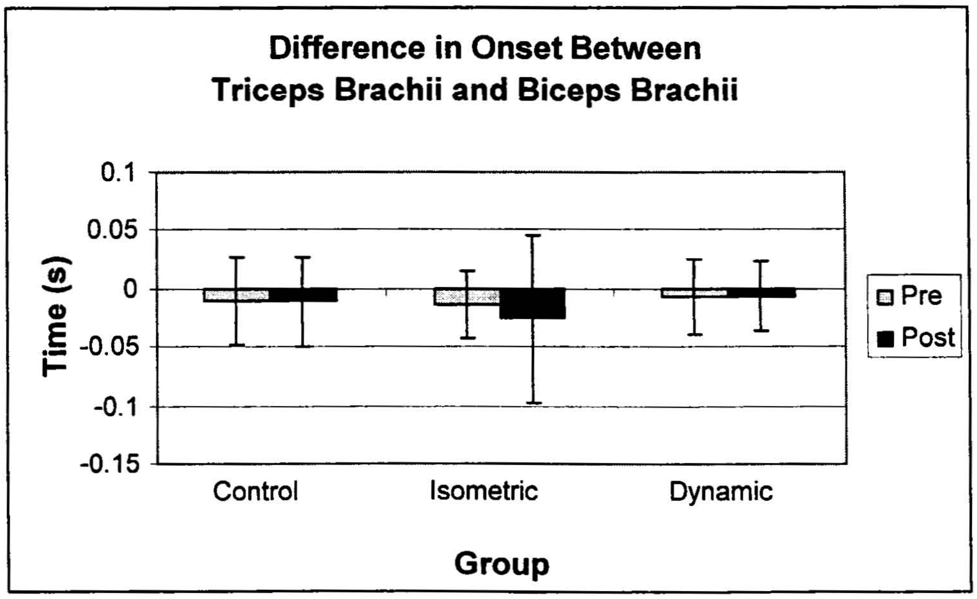

Figure III: Difference in onset time between triceps brachii and biceps brachii, pre- and post-training. Columns and bars represent means and standard deviations, respectively.

4. Reaction Time

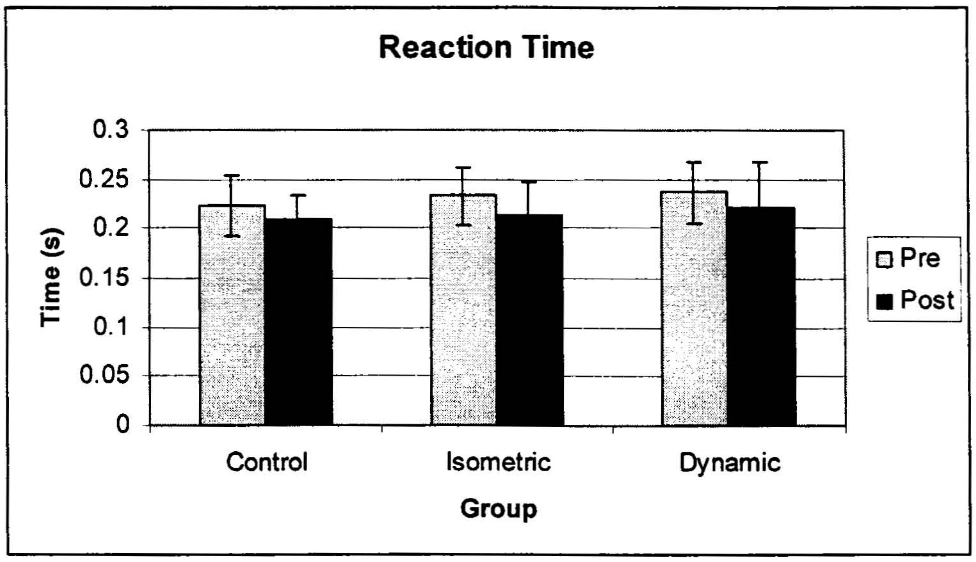

Figure IV: Reaction time, pre- and post-training. Columns and bars represent means and standard deviations, respectively.

5. Quick Hands Test

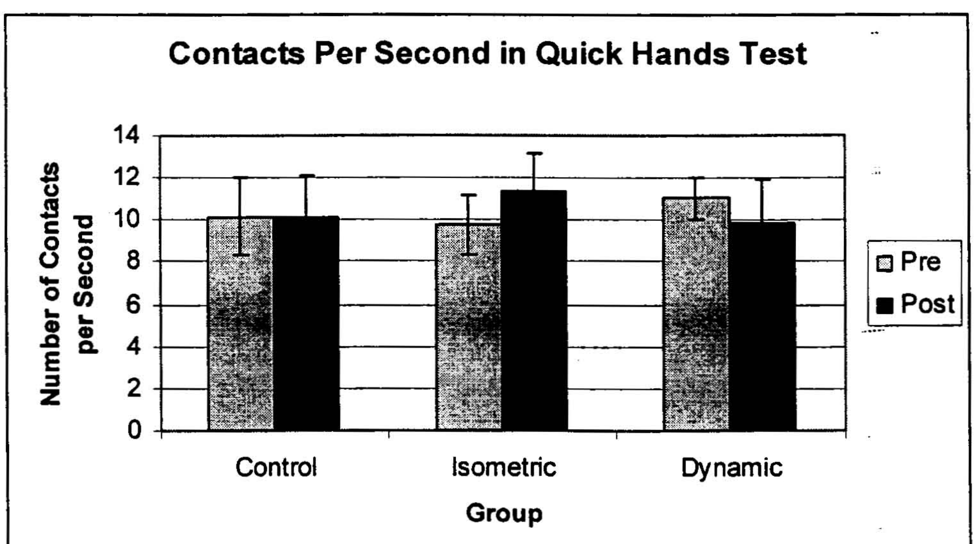

Figure V: Number of contacts per second, pre- and post-training. Columns and bars represent means and standard deviations, respectively.