RESISTANCE EXERCISE FOR ENHANCING SPEED/POWER PERFORMANCE

THE ROLE OF HIGH RESISTANCE EXERCISE IN ENHANCING SPEED/POWER PERFORMANCE

BY

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This thesis is dedicated to...

my parents, Peter and Ismini Ioannidis
for their encouragement, love and support.

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CHAPTER 1

ADAPTATIONS TO BALLISTIC VERSUS HEAVY RESISTANCE TRAINING

1.0 INTRODUCTION

Ballistic movements are actions with very short movement times, and very high velocities and accelerations. Ballistic movements originate from preprogrammed commands without modification from sensory feedback (Desmedt & Godaux, 1979). In terms of athletic movements, high velocity power actions such as jumping, throwing, and striking are considered ballistic.

Heavy resistance movements are actions with high loads and low velocities. This type of movement may be classified under ramp contractions, that occur with continuous peripheral feedback and therefore can be modified by sensory feedback (Zehr & Sale, 1994).

The characteristic properties of both movement types may be altered by training. Conventional heavy resistance training involves slow actions with near maximal loads, and with loads of no less than 60% of the one-repetition maximum (1 RM) (Sale & MacDougall, 1981). In comparison, ballistic training consists of fast actions with a high rate of force development against a relatively low resistance. In terms of maximal loads, ballistic training usually ranges from 0 to 30% of the 1 RM (Bauer et al., 1995; Wilson et al., 1993).

A persistent issue in the training of athletes is how to develop the most effective method for increasing speed and power performance. Several methods have been created and used with some success. These methods range from high resistance exercise (weight lifting) to high speed "ballistic" exercise with very light loads (resistance). Other methods, such as simply "practising" the actual sport movements or training with load-velocity combinations that produce maximal muscle power output have been used. All of the above training methods vary with regards to the absolute loads that are utilized. For example, it is considered by some investigators that the development of maximum power requires training loads equivalent to ~30-50% of maximum isometric force (Mastropaolo, 1992; Moritani, 1993). In comparison, heavy resistance and high speed ballistic exercise are normally performed with loads of 80-100% and 0-30% MVC, respectively.

Therefore, the question raised is which method is best for a particular sport activity? For one particular group of athletes, the solution to this question is especially not clear. These athletes require high speed capabilities against relatively light loads, such as in kicking a ball, swinging a racket, throwing a javelin, and punching and kicking actions associated with boxing and martial arts. It might at first seem that the athletes should train with ballistic actions against very light loads (0-30% of MVC), in accordance with training velocity specificity (Kaneko et al., 1983). However, this training regimen may preclude strenghtening (hypertrophy) of type II (fast twitch) fibres, a potentially valuable adaptation. The benefit of fast fibre hypertrophy would be the potential for greater force and acceleration at the beginning of a ballistic movement.

Evidence in favour of both light and heavy training loads can be found throughout the literature; however, there is not yet any clear resolution to the issue. This review will be divided into three distinct sections which include: motor control, motor unit activation and training adaptations. The motor unit activation section will be further divided into ramp and ballistic actions focusing on agonist (Ag) and antagonist (Ant) activation and burst patterns. The section on training adaptations will be further divided and will focus on performance, muscle, and neural adaptations.

2.0 MOTOR CONTROL

In central nervous system (CNS) control of voluntary contractions, the motor cortex regulates both the muscle to be activated and intensity of activation, while the cerebellum and basal ganglia control the force and rate of force development by controlling the transmission of discharges to the active muscle (Hamada, 1981).

Heavy resistance actions may be classified as ramp contractions, if the movement produces force at a relatively slow rate. Ramp movements are influenced by peripheral feedback. In contrast, ballistic movements are preprogrammed and are not modified by sensory feedback. Therefore, it has been suggested that ramp and ballistic motor control involve different higher brain structures. The basal ganglia functions in generating slow voluntary ramp actions, while the cerebellar cortex is the cortical area involved in the preprogramming and initiation of ballistic actions. (Kornhuber, 1971, cited in Desmedt & Godaux, 1978). Animal research done on monkeys performing ballistic, rapidly alternating and tracking actions, also supports the notion that the cerebellum performs a specialized role in ballistic action (Ivry et al., 1988), whereas the basal ganglia are involved in the control of slow ramp actions (Delong & Strick, 1974).

Since ballistic and ramp (heavy resistance) actions are controlled from different neural areas, it may be expected that ballistic and heavy resistance training could elicit different neural adaptations.

3.0 MOTOR UNIT ACTIVATION

As described above, the CNS acts differently in ramp and ballistic actions such that the intensity of motor unit (MU) activation (the number of motor units recruited and the mean firing frequencies of all motor units), the duration of activity, and pattern of activation differ between ballistic and ramp contractions.

The relative importance of these factors varies with ballistic and ramp movements. Therefore, during heavy resistance or ballistic training, these factors may adapt differently.

3.1 RAMP ACTIONS/ WEIGHT TRAINING

The fastest ramp contractions last for about 500 ms, while the corresponding Ag EMG burst may last for the full duration of the contraction. The burst pattern in ramp contractions is characterized by varying interspike intervals. For example, at the beginning of a slow ramp contraction, MUs may fire one or more double discharges (doublets) before initiating the single-spike firing pattern (Bawa & Calancie, 1983). All MUs have minimum and maximum firing rates, which are dependent on the type of muscle contraction. A slow ramp contraction (heavy resistance movements) has an average minimum MU firing rate of ~ 6-8 Hz. Maximum rates, during sustained maximum voluntary contractions, range from 10-60 Hz (Edstrom & Grimby, 1986). The large range in minimum and maximum firing rates is due, in part to differences among MUs and muscles. Proximal limb muscles tend to have lower maximum MU firing rates compared to small distal muscles (Burke et al., 1976).

In a ramp contraction of increasing force, the recruitment of motor units is thought to depend on the size of the motor neuron (soma). Smaller neurons with slower conduction velocities are recruited before larger neurons with higher conduction velocities (Milner-Brown et al., 1973). Therefore, as the strength of a contraction increases, progressively larger motor units are recruited. This recruitment order is in accordance with the size principle of recruitment, first proposed by Henneman and colleagues (1965).

3.2 BALLISTIC ACTIONS

A high rate of torque development is required during ballistic movements. However, the rate of torque development is not related to the velocity of movement or the external load but to an effort to produce force quickly (Desmedt & Godaux, 1977). For example, Behm and Sale (1993) found that as long as the intent is to move quickly, even an isometric action can cause high rates of force development. Although heavy resistance and ballistic training can attain high rates of torque development, generally, only ballistic training demands a maximal rate of torque development.

Ballistic actions demonstrate a triphasic pattern of agonist (Ag1), antagonist (Ant1), and agonist activation (Ag2) (Angel, 1975; Cooke & Brown, 1990; Feldman et al., 1995; Palmer et al., 1994). This triphasic pattern is also evident in ballistic isometric actions in the elbow flexors and extensors (Gordon & Ghez, 1984). The transition to the triphasic activation pattern is influenced by movement time. Brown and Gilleard (1991) examined the Ag1 burst patterns during slow and fast movements. They found that the distinct triphasic pattern occurred most regularly when movement time was less than 400 ms. The triphasic pattern begins with the Ag1 burst, which is thought to accelerate the movement. This is then followed by the Ant1 burst, which acts to decelerate the movement. The final stage is the Ag2 burst, which halts the negative deceleration produced by the Ant1 burst (Cooke & Brown, 1990). Since the first documentation of the triphasic pattern, further research has provided information on factors which influence the duration of the individual burst patterns (Angel, 1975; Gordon & Ghez, 1984; Marsden et al., 1983; Mustard & Lee, 1987). One such factor is unexpected load when performing ballistic actions. Angel (1975) found that when movement was artificially impeded, there was no evidence of a silent period between Ag1 and Ag2. It was concluded that the size of the silent period and of Ag2 may be altered by peripheral feedback, whereas Ag1 is preprogrammed centrally. The size of the Ant1 is influenced by a number of factors which include load (Mustard & Lee, 1987), velocity of movement (Marsden et al., 1983) and precision of movement (Gordon & Ghez, 1984). Therefore, the Ant1 burst pattern is also influenced by peripheral feedback.

Ballistic actions last for about 80-150 ms (time to peak force), while the EMG burst may last for approximately 100 ms and cease before peak force is reached (Desmedt & Godaux, 1979). In addition, the interspike intervals progressively increase throughout the EMG burst duration. The interspike pattern may vary with the rate of force development; the interval between the first two spikes in the burst is shorter than ensuing intervals as the rate of force development increases (Desmedt & Godaux, 1977). The force thresholds of MUs are lower in ballistic actions (Desmedt, 1981; Desmedt & Godaux, 1978). Furthermore, during brief maximal ballistic actions, MUs may fire at initial frequencies of up to 120 Hz (Desmedt & Godaux, 1977). These high burst firing frequencies are much higher than those which are required for maximum force production in a sustained contraction (50 Hz) (Grimby et al., 1981). Although in a sustained maximal contraction, peak force may not be influenced by these high firing frequencies, the rate of force development may be increased (Zehr & Sale, 1994). In addition, it has been hypothesized that firing frequency is the main regulator of power during ballistic actions (Edstrom & Grimby, 1986).

Desmedt (1981) has indicated that with fast ballistic contractions, the recruitment order is maintained, in accordance with the size principle whereas other researchers have found selective activation of high threshold fast units as movement velocities increase. Nardone and Schieppati (1988) studied the human triceps surae and found a shift in activation from soleus (slow muscle) to lateral gastrocnemius (fast muscle) during lengthening actions of increasing velocity. Grimby and Hannerz (1977, 1974) reported selective activation of fast MUs during rapid movements in humans. However, selective activation only occurred when the subject was relaxed prior to a maximal rapid, short duration movement.

Grimby and Hannerz (1977, 1974) suggested that selective activation of fast motor units is beneficial for rapid relaxation of the muscle on termination of movements. Furthermore, it may be possible that slow motor units with longer relaxation times might impair high speed actions. This assumption may hold true particularly for fast alternating movements (Edstrom & Grimby, 1986). Smith et al. (1980) observed selective activation of fast twitch muscle as well as inhibition of slow twitch muscle during rapid paw shakes in cat ankle extensors, but found neither of these during normal locomotion.

The apparent reversal of recruitment order between fast and slow motor units found in a few studies may be due to methodological and measurement errors. It has been suggested that due to a larger axon, a fast motor neuron may depolarize immediately after a slow one, but will conduct its nerve impulse more rapidly to the muscle fibres, and may therefore be the first to evoke muscle action potentials. This gives the appearance of a reversal in recruitment order (Desmedt, 1981).

It has been observed that, prior to rapid ballistic actions, there is a depression or silencing of EMG activity which has been named premovement depression (PMD) (Zehr & Sale, 1994). PMD occurs 40-50 ms before the Ag1 burst and can only be seen when there is low level tonic muscle activity prior to a ballistic action. This EMG depression has been reported for both antagonist and agonist muscles (Conrad et al., 1983; Yabe, 1976). However, PMD does not always occur prior to a ballistic action. It has been reported to happen ~ 30% of the time for upper limb muscles and ~ 50% of the time for lower limb muscles (Yabe et al., 1978, cited in Aoki et al., 1989).

PMD is a phenomenon which is exclusively related to ballistic actions. Wierzbicka et al. (1993) were able to record agonist PMD during isometric, ballistic elbow flexion. Therefore, the intent to perform a ballistic action with maximum rate of force development determines whether or not PMD occurs, rather than the ensuing mechanical event itself.

Nishizono and Kato (1987) examined the occurrence of PMD during the highly skilled act of the archery release. It was found that the frequency of PMD was higher in the group of highly skilled archers than that of the less skilled archers. This was confirmed by Walter (1989), who showed that subjects were able to voluntarily control the agonist PMD with biofeedback training.

Shibata and Moritani, (1991) (cited in Moritani, 1993) had subjects respond to a flashing light signal by performing a plantar flexion as rapidly as possible. They found that maximal rate of force development was significantly greater during the ballistic action with PMD. In addition, the duration of PMD has been shown to be positively correlated with maximum movement velocity (Conrad et al., 1983). The positive relationship between PMD, rate of force development and maximum movement velocity is thought to be caused by an increased synchronization of the motor neuron pool. This allows the motor neurons to be brought into a nonrefractory state, which enables all the motor neurons to fire at the same time at lower minimum force thresholds and with a higher initial frequency (Conrad et al., 1983).

4.0 TRAINING ADAPTATIONS

An understanding of how ballistic and heavy resistance training affects athletic performance may only be determined by examining both peripheral (muscular) and central (neural) adaptations.

4.1 PERFORMANCE ADAPTATIONS

It is well accepted that if training is to be effective in sport, it must be specific to the task of that sport. Based on this knowledge, athletes and coaches should attempt to determine and acquire individual, sport specific training programs. The training effect of different loads on the force-velocity relation in human muscle has been extensively studied. For example, Kaneko et al. (1983) have reported that a training load of 30% MVC was most effective in increasing maximal power output, while training at 100% MVC was most effective for increasing maximum strength, and training with no external load and at maximum velocity was most effective for increasing maximum velocity. They suggest that different training loads will bring about specific modifications of the force-velocity relation. These observations, confirmed by others, have led to the formulation of the specificity of velocity training principle in strength training. Additional supporting evidence for this principle is reviewed below.

Caiozzo et al. (1981) trained subjects for 4 weeks, 3 times a week, performing 2 sets of 10 maximal leg extensions on a Cybex dynamometer at a velocity of either $96°\cdot s^{-1}$ or $240°\cdot s^{-1}$. They found that the "slow" group showed more improvement at the lower velocities tested and had smaller but significant improvements throughout the range of higher speeds, with the exception of the highest velocity tested, ($288°\cdot s^{-1}$). The "fast" group demonstrated smaller, more uniform improvements that were specific at the training speeds of $288°\cdot s^{-1}$, $192°\cdot s^{-1}$ and $144°\cdot s^{-1}$. Kanehisa and Miyashita (1983) divided subjects into 3 training groups, consisting of a slow ($60°\cdot s^{-1}$) fast ($300°\cdot s^{-1}$) and intermediate group ($180°\cdot s^{-1}$). The groups were tested at 60, 120, 180, 240 and $300°\cdot s^{-1}$ and trained for 8 weeks. The results showed that each group improved the most at the test speeds specific to their training velocity. The slow and intermediate groups showed increases at all test speeds. These increases were less pronounced at higher speeds, while the fast group improved at 240 and 300°·s^{-1} only. In a study, by Coyle et al. (1981) subjects trained isokinetically at different velocities and found that it was easier to make slow velocity strength gains than fast velocity strength gains with velocity specific training. Slow training was found to be highly specific, while fast training was found to produce similar improvements at all test speeds.

Baker et al. (1994) had subjects weight train for 12 weeks and measured dynamic (low velocity strength) and isometric strength. They found that the mechanism(s) that contributed to an enhanced dynamic strength appeared to be unrelated to the mechanism(s) that contributed to an enhanced isometric strength. These studies reiterate the principle that task specific strength methods elicit the largest improvements when compared to that of a less accustomed exercise (Sale & MacDougall, 1981).

Specificity of velocity studies have produced varying results and generated different conclusions as to the transferability of a training velocity. This variation is probably due to differing training protocols and testing procedures. However, the principle of a velocity specific response to training remains valid. Specificity of training research suggests that the greatest increase in force production occurs at velocities similar to the training velocity. However, a superior method for promoting improvement in athletic performance may be obtained by a combination of a sport specific and supplementary training program.

Most specificity of training studies use single training methods, which differ from the multiple training protocols and/or loads which are used during combined training. A knowledge of how combined training influences specificity would be beneficial to both the coach and athlete who are seeking the best method to achieve elevated performance levels.

Wilson et al. (1993) have investigated different training protocols in order to find the optimal method for improving sprinting and vertical jumping performance. Their study compared the relative effectiveness of heavy resistance training (squat, 6-10 RM), drop jump training (from 20-80 cm) and jump squat training (with loads equal to ~30% of maximum isometric force). Results showed that only the jump squat training showed a significant improvement in 30 m sprinting. Furthermore, vertical jump performance improved with all three training methods, but the jump squat training produced the best results. The results for vertical jump performance confirmed a study reported earlier by Berger (1963). Berger (1963) measured vertical jump height after 4 different training regimens. Group one trained using a 10 RM squat (dynamic heavy resistance) protocol, group two trained with 50 to 60 percent of 10 RM for ten repetitions of jumping squats (combined resistance training with jump training), group three trained statically (static heavy resistance) and group four trained by jumping vertically (ballistic training). The investigator found that squat jumping improved vertical jumping to the greatest extent, whereas training by vertical jumping did not increase vertical jump performance. This result suggests that combined training was more effective in improving jumping performance as compared to ballistic training alone. Schultz (1967) evaluated the effect of combined training on standing broad (long) jump development. Schultz (1967) found that direct broad jumping practice, or broad jumping plus sprinting or resistance training, was superior to resistance training alone. This suggests that weight training has little effect on broad jumping performance.

Whitley and Smith (1966) designed an experiment to compare the effects of heavy resistance training, dynamic overload training (moving a weighted box as fast as possible) and free swing training (swinging their arms as fast as possible) on the speed and strength of a lateral swinging arm movement. They reported that, in order to increase swing speed of the arm, heavy resistance training was equally effective as dynamic overload training alone. Following training, arm swing speed and strength significantly increased, but only in heavy resistance and dynamic overload training. This study suggests that increasing the strength of the muscle (resistance training) increases velocity of movement.

Considerable controversy is evident throughout the literature related to the effects of combined training on strength and speed of movements. This may be due to different muscle groups and movement patterns trained, and to different combinations of training intensity and speed.

4.2 MUSCULAR ADAPTATIONS

4.2.1 Twitch Contractile Properties

A muscle twitch represents a motor unit's response to a single impulse and can be characterized by several physiolological twitch contractile properties. These contractile properties may be affected differently by different modes of training.

Alway et al. (1989) isometrically trained the plantar-flexors of sedentary individuals for 16 weeks. They found that after resistance training, twitch contraction time decreased by ~ 20%, whereas one half relaxation time and peak twitch torque (PT) remained unchanged. They argued that there were no changes in PT after resistance training due to increased muscle elasticity. Thus, if a muscle is more elastic, a relatively longer time will be required to take up the elastic component before the onset of twitch torque (Alway et al., 1988). Changes in twitch contractile property dynamics may be caused by selective type II fibre hypertrophy, changes in percent fibre type, % fibre volume of the SR, or qualitative changes in the SR which affect Ca^{++} release and reuptake (Alway et al., 1989). However, Ishida et al. (1990) found no changes in contractile properties with 6 weeks of resistance training of the calf muscles.

Behm and Sale (1993) trained subjects to attempt to execute a ballistic dorsiflexion action as rapidly as possible. They found that time to peak torque and half relaxation time decreased.

Only one study measured both twitch and tetanic contractile properties. Duchateau and Hainaut (1984) had subjects train their adductor pollicis with either isometric (heavy resistance) or dynamic resistance exercise (fast isotonic dynamic contractions) for 3 months. Electrical and mechanical responses of the adductor pollicis were recorded during supramaximal electrical stimulation of the ulnar nerve at the wrist. They found that dynamic training produced a 13% greater rate of tetanic torque development as compared to isometric training. Dynamic training also resulted in greater increases in maximal shortening velocity and greater increases in twitch rate of torque development, with smaller increases in peak torque compared to isometric training. The researchers concluded that human muscle adapted differently to isometric and dynamic training (training mode specificity response).

Caution should be taken when interpreting evoked twitch contractile measurements. For example, the biceps muscle of resistance trained subjects may bulge and affect evoked twitch contractile properties at different joint angles compared with sedentary subjects; thus, muscle group, joint angle of the muscle and resistance training may influence evoked twitch contractile properties (O'Hagan et al., 1993; Tsunoda et al., 1993).

4.2.2 Hypertrophy

Training-induced hypertrophy is caused mainly by the enlargement of existing muscle fibres, thereby increasing the cross-sectional area of the muscle (MacDougall, 1986). Skeletal muscle enlargement may also be the result of hyperplasia, which is an increase in the number of muscle fibres (Antonio & Gonyea, 1994; Mikesky et al., 1991). However, most experimental data suggest that strength training of human subjects causes only hypertrophy of existing fibres and not hyperplasia (MacDougall et al., 1984).

The magnitude of hypertrophy depends on several factors, which include the initial training status of the individual, the duration of the training, and the intensity and mode of training. Davies et al. (1988) found that 6 weeks of isometric training increased the cross-sectional area of the elbow flexors by ~ 5%. Moreover, Garfinkel and Cafarelli (1992) found that 8 weeks of isometric training increased quadriceps cross-sectional area by 15%.

Dynamic training produces similar results. Narici et al. (1989) had subjects train the leg extensors on a isokinetic device at a slow velocity for 60 days. They found that the cross-sectional area of the quadriceps increased by 8.5%. Five months of heavy resistance training increased both fast twitch and slow twitch muscle fibres in the triceps brachii by 33% and 27%, respectively (MacDougall et al., 1979). Hypertrophy occurs in both main fibre types but seems to be greater in fast twitch fibres (MacDougall et al., 1980; Tesch, 1988). As a consequence, the type II/I area ratio increases in resistance trained subjects (Sale et al., 1987).

High training intensities are generally considered necessary to cause hypertrophy, because the resultant, high force production is suggested as a stimulus for hypertrophy (Jones, 1992). Conversely fast velocity training, with low force output, would be expected to produce little or no hypertrophy. Nevertheless, research has shown increases in fast twitch fibre area with high velocity training and no changes in fibre area with slow velocity training. For example, Coyle et al. (1981) had males perform maximal two-legged isokinetic knee extensions three times per week for 6 weeks at either $60° \cdot s^{-1}$, $300° \cdot s^{-1}$ or at both velocities. They found that training at $300° \cdot s^{-1}$ caused a significant enlargement of type II muscle fibres, with a concomitant improvement in peak torque at both fast and slow velocities. However, it can be argued that a training velocity of $300° \cdot s^{-1}$ should be considered as a intermediate speed causing the highlv transferable results (Houston & Goemans, 1982). Others have found no significant increase in either slow or fast twitch fibre area resulting from slow and fast velocity resistance training (Ewing et al., 1990). Although there are conflicting reports as to the extent of hypertrophy with different training methods, it appears that hypertrophy of human skeletal muscle occurs in heavy resistance training, whereas there is little or no increase in muscle size with ballistic training.

Training induced muscle hypertrophy may decrease maximal contraction velocity, in part due to increases in fibre pennation angle or angle of tendon attachment. This is supported by Tesch and Larsson (1982), who showed through a cross-sectional study that bodybuilders and weight lifters possessed impaired torque generating ability at high velocities. However, impaired high velocity strength, as a result of hypertrophied muscle, may be caused by specific neural adaptation resulting from slow velocity strength training.

4.2.3 Fibre Type Conversion

Within skeletal muscle, there exist different types of muscle fibres, with properties that are uniquely suited for specific types of activities. There are two main fibre types, slow twitch (ST) or type I and fast twitch (FT) or type II. Histochemical methods may discriminate between fast and slow fibre types, by identifying the possible existence of metabolic differences in the profiles of ST and FT fibres; based on differences in actomyosin ATPase activity remaining in myofibrils after preincubation in an acid or alkaline medium (Brooke & Kaiser, 1970). The histochemical analysis of muscle has identified additional fibre subtypes. The most commonly cited are ST (I), FTa (IIa), FTb (IIb) and FTc (IIc) as proposed by Saltin et al. (1977). However, a more recent investigation using an animal model has further delineated fibres into ST (I), STc (Ic), FTc (IIc), FTa (IIa), FTab (IIab), FTb (IIb) (Staron & Pette, 1986). Research has shown that fibre composition affects the shape of the force velocity relation, particularly at higher velocities. Tihanyi et al. (1982) found that a group of subjects possessing 50% or more fast twitch fibres in the vastus lateralis muscle, produced more strength and power at higher angular velocities than did a group who had less then 50% fast twitch fibres. Coyle et al. (1979) showed that subjects with a large proportion of type II fibres generated 11, 16, 23 and 47% greater torque at velocities of 115, 200, 287, $400° \cdot s^{-1}$ than subjects with a larger number of type I fibres. Therefore, it would be expected that a high percentage of fast twitch fibres would be more beneficial to ballistic action (with fast contraction times) than slow heavy resistance actions.

The adaptability of mammalian skeletal muscles is reflected in its capability to undergo extensive remodelling to altered functional and metabolic demands. Animal research has found that low frequency (10 Hz) nerve stimulation (24 hr/day) can transform fibres from type IIb → IIa → I (Pette, 1984). On the other hand, high frequency stimulation (100 Hz) transforms fibres from type I → IIa → IIb (Lomo, 1986).

However, the conversion of type I to II fibres is not as complete as type II to I conversion (Pette, 1984). Human research has found that resistance training or ballistic training may also induce fibre conversion.

Wang et al. (1993) had subjects strength train the muscles of the lower limb for 20 weeks. The proportion of IIb fibres decreased with a concomitant increase in IIa muscle fibres. Furthermore, biopsies taken from bodybuilders, showed that compared to sedentary controls, bodybuilders possess a higher proportion of muscle with a coexistence of myosin heavy chain (MHC) IIa and IIb types, with nearly no skeletal fibres possessing exclusively MHC IIb (Klitgaard et al., 1990). Resistance training does not appear to transform muscle from type I to II but converts IIb to IIa fibres. The conversion to IIa fibres appears to occur because of a shift in the myosin profile in the IIb fibres. An increase in the population of IIa fibres would increase the oxidative capacity of the muscle, thereby increasing muscular endurance (Hather et al., 1991; Staron et al., 1991). A necessary requirement for IIb to IIa muscle fibre transformation appears related to absolute recruitment time. Green and colleagues (1979) have demonstrated, through examination of glycogen depletion patterns in human muscle, that the recruitment of IIb fibres is dependent on the duration and intensity of the activity. It has been shown that high intensity resistance training involves all fibre types. Furthermore, Tesch (1991) found greater glycogen depletion in type II compared to type I fibres and a significantly greater number of type II fibres that were glycogen depleted, after a session that included: 5 sets of 6 to 12 reps of squats, seated leg extensions and leg press exercises. The results, of a study by Staron et al. (1991, 1994) indicate that fibre transformation takes place extremely early (~ 28 days) during the course of the training period.

Given the specific burst patterns during ballistic movements, ballistic training may be expected to cause fibre-type transformation from I → IIa → IIb. Jansson et al. (1990) had subjects perform repeated 30 s Wingate tests on a cycle ergometer for 4 to 6 weeks. They found that the number of type I fibres tended to decrease, with a simultaneous increase in the percentage of IIa fibres. There were no significant changes in either IIb or IIc fibres. Jansson et al. (1990) suggested that fibre transformation, as a result of sprint training, may be related to increased motor unit firing frequencies. Esbjornsson et al. (1993) had male subjects train on a cycle ergometer. Each training session consisted of fifteen 10-s bouts of maximal voluntary cycling. After the 6 week period, the number of I and IIb fibres fell, with a concurrent increase in the population of IIa fibres; this partly confirmed Jansson et al.'s (1990) study. However, in contrast, a conversion from type IIb to IIa also occurred. Andersen and co-workers (1992) studied the effects of sprint training on MHC isoform composition in skeletal muscle. After training, sprinters showed a decrease in muscle fibres displaying only slow MHCs, and a co-existence of IIa and IIb MHC isoforms. A large increase in IIa MHC isoforms was also seen; this suggests that sprint training increases the expression of IIa MHC isoforms as a result of a bi-directional conversion from IIb → IIa ← I MHC isoforms.

A fibre conversion of IIb → IIa fibres would slow muscle contraction speed, based on the data of Larsson and Moss (1993). The investigators found that IIb fibres may be three times as fast as IIa fibres, which implies that this transformation may have a detrimental effect on ballistic performance.

Other high velocity intermittent training studies have failed to show fibre type conversion (Allemeier et al., 1994; Thorstensson et al., 1975). This may be due muscle mass size or variations in fibre composition from biopsy to biopsy. Moreover, Thorstensson et al. (1975) trained subjects with bouts lasting five seconds; the duration of training may not have been long enough to cause a fibre conversion.

In summary, it appears that heavy resistance training transforms IIb to IIa fibres, while slow twitch fibres remain unchanged. However, sprint type (ballistic) training seems to have varying effects on muscle fibres; ranging from no effect whatsoever to conversion to IIa from both IIb and I fibres.

4.3 NEURAL ADAPTATIONS

4.3.1 Agonist Adaptations to Resistance Training

Frequently in strength and power training, participants display rapid and marked increases in strength. These increases have been attributed to neural adaptations because muscular adaptation cannot account for the rapid strength gains (Hakkinen & Kauhanen, 1989; Moritani, 1993; Moritani & deVries, 1979; Sale, 1988). Neural adaptations may explain the marked specificity seen in movement pattern, joint angle and velocity and may be caused by increases in muscle activation (Sale & MacDougall, 1981).

Following a period of strength training, increases in force are accompanied by increases in muscle activation (EMG) (Hakkinen & Komi, 1983; Komi et al., 1978; Moritani & deVries, 1979). Narici et al. (1989) have attributed this increased EMG to neural factors residing in the inhibitory or facilitory synaptic pathways, which act to disinhibit higher cortical centres or to inhibit the Renshaw cell and Golgi tendon organ reflex. Westing et al. (1988) have suggested an inhibitory feedback loop in low velocity, high force contractions. This mechanism, if active, can reduce force production. Low velocity training possibly raises the low velocity portion of the curve through a disinhibition response to training (Caiozzo et al., 1981). There are two types of nerves, inhibitory and excitatory. Astrand and Rodahl (1986) describe disinhibition as occurring when an inhibitory neuron becomes subject to the influence of other inhibitory neurons. This action may cause the inhibitory neuron to remain inactive allowing the nerve cell which it inhibits to respond. Moritani and deVries (1979) describe this as learning to disinhibit.

Synchronization of MUs may be another adaptation to resistance training. Milner-Brown et al. (1975) defined synchronization as the coincident firing times of two or more motor units. In other words, a high degree of synchronization will cause motor units to discharge action potentials at the same time. Synchronization of motor units will increase maximum integrated EMG activity, while desynchronization of motor units will reduce integrated EMG activity because of overlapping and thereby, cancelling each other's individual action potentials when recorded from surface electrodes (Jones, 1992).

Komi and Buskirk (1972) found that early in a resistance training program, there is an increased recruitment of synchronously contracting motor units, which lasts one to three weeks. Milner-Brown et al. (1975) have found weight lifters to have a higher degree of synchronization than controls. A host of other recent studies have suggested based on changes in EMG patterns that synchronization increases with strength training (Duchateau & Hainaut, 1984; Kanehisa & Miyashita, 1983; Narici et al., 1989; Sale et al., 1983). However, synchronous firing has never been shown to increase rate of force development (Miller et al., 1981), nor to produce any force advantage over asynchronous firing, and at sub-maximum frequencies, asynchronous firing produces more force (Lind & Petrofsky, 1979; Rack & Westbury, 1969).

Other researchers have found no evidence to suggest that increased force was due to neural adaptations (Cannon & Cafarelli, 1987; Garfinkel & Cafarelli, 1992; Thorstensson et al., 1976). A nonhypertrophic increase in force may be explained by increases in radiologically assessed packing density of fibres. There is also speculation that the angle of pennation of individual fibres might adapt so that they become more parallel to the direction of pull (Jones & Rutherford, 1987).

4.3.2 Agonist Adaptations to Ballistic Training

EMG activity may also be influenced by ballistic actions. Barnes (1980) showed that motor unit activity decreased with increasing isokinetic velocities. EMG activity may be expected to be less at higher velocities if slow twitch units are suppressed (biased activation of fast twitch units). Therefore, increases in high velocity strength may be due to increases in general motor unit activation. In contrast, other investigators have found that, during leg extension movements, muscle activation increases with increasing velocity (Seger & Thorstensson, 1994). This may be expected because of higher firing rates or because of greater synchronization of units at higher velocities and no "drop-out" of type I units.

Hakkinen et al. (1985) demonstrated EMG training specificity with ballistic training. Explosive jump training caused a significant increase in EMG during the start of motor unit activation while conventional heavy resistance training produced a small increase in EMG later in the activation period. A specific high velocity training effect was also found by Hakkinen and Komi (1986). These researchers compared ballistic type training to conventional heavy resistance training. They found that only ballistic training resulted in a greater rate of force development after training. However, they found increases in EMG activity with only weight training and not jump training.

It has been speculated that ballistic actions rely heavily on increased motor unit firing frequencies to develop force rapidly and to achieve a large peak force (Desmedt, 1981). Therefore, it may be expected that training for velocity-specific adaptation may focus upon altering the motoneuron firing frequencies of the ballistically trained muscles. Kanehisa and Miyashita (1983) suggest that synchronous firing is the key component in increased power output in dynamic contractions, although the rate of force development in brief maximal contractions is faster with voluntary than with evoked tetanic contractions (synchronous) (Miller et al., 1981). The role of synchronous firing, as a neural adaptation to ballistic training, remains unclear. In comparison, synchronization of motor unit recruitment may be beneficial to ballistic actions, by reducing the force activation threshold of MUs (Desmedt & Godaux, 1978).

Most studies suggest that EMG increases with heavy resistance training and ballistic training are the result of an increase in motor unit recruitment, firing frequencies and/or increased synchronization. However, it appears that firing frequency adaptation or even selective activation of fast twitch motor units, may be more critical during ballistic training.

4.3.3 Antagonist Adaptations to Resistance Training

Antagonist activation also adapts with training. There is typically some EMG activity in the antagonist muscle during maximum voluntary contraction. Coactivation occurs primarily in complex movements, and may be influenced by joint angular velocity (Osternig et al., 1986), joint angle, and contraction type (eccentric or concentric) (Snow et al., 1993). Coactivation is assumed to reduce the net force produced by the agonist by generating an opposing force which acts to impede movement. In addition, antagonist activation may also impair the ability of the agonist to fully activate all motor units, by reciprocal inhibition (Sale, 1988).

Carolan and Cafarelli (1992) measured EMG activity of the antagonist during maximum isometric knee extension and found that it was as much as 22% of agonist EMG activity. Furthermore, Carolan and Cafarelli (1992) had subjects isometrically resistance train the knee extensors for 8 weeks. They found that coactivation of the antagonist (biceps femoris) decreased by approximately 20% after the first week and decreased only slightly more during the remaining 7 weeks of training.

4.3.4 Antagonist Adaptations to Ballistic Training

During ballistic actions, the triphasic (Ag1, Ant1, Ag2) EMG burst pattern overlaps, resulting in antagonist-agonist coactivation (Cooke & Brown, 1990; Marsden et al., 1983). Osternig et al. (1986) isokinetically tested subjects during knee extensions at an angular velocity of 100 and 400° $\cdot s^{-1}$. They found that coactivation was significantly greater at the fast versus the slow velocity. Additional support comes from Snow et al. (1993). They found that coactivation was greater at 90 compared to 30°$\cdot s^{-1}$ for both concentric and eccentric knee extension actions. Waters and Strick (1981) observed that antagonist coactivation was greater when precise termination of the movement was necessary, compared to a non-precise termination of the movement.

Although coactivation would seem detrimental to producing high agonist torques and velocities, it may function as a joint stabilizer, a protective mechanism against injury, as well as a mechanism that acts to decelerate the limb in ballistic actions (Jaric et al., 1995; Marsden, et al., 1983). For example, Osternig et al. (1986) found that coactivation of the antagonists could possibly be beneficial. In rapid, repeated movements, compared to distance runners, sprinters possessed more coactivation of antagonists at the knee joint. Sprinters have greater frequency and force in their strides, indicating that coactivation of antagonists plays a greater role in injury prevention. Furthermore, antagonist coactivation would allow the stretch-shortening cycle to be utilized.

5.0 SUMMARY

Ballistic movements are actions with the shortest movement times, and highest velocities and accelerations. Ballistic movements originate from preprogrammed commands without modification from sensory feedback (Desmedt & Godaux, 1979).

Heavy resistance movements are actions with high loads and low velocities. Heavy resistance movements are classified under ramp movements and occur with continuous peripheral feedback and therefore can be modified by sensory feedback (Zehr & Sale, 1994).

Heavy resistance training involves slow actions with near maximal loads, and with loads of no less than 60% of the one-repetition maximum (1 RM) (Sale & MacDougall, 1981). In comparison, ballistic training consists of fast actions with a high rate of force development against low resistance. In terms of maximal loads, ballistic training usually ranges from 0 to 30% of the 1 RM (Bauer et al., 1995; Wilson et al., 1993).

Ramp and ballistic motor control involve different higher brain structures. Therefore, ballistic and heavy resistance training are expected to cause distinct and specific peripheral and central adaptations.

Heavy resistance training alters the twitch contractile properties of human muscle differently than ballistic training. Moreover, heavy resistance training produces hypertrophy of muscle, whereas there is little or no increase in muscle size with ballistic training. Training also induces fibre type conversion. It appears that heavy resistance training transforms IIb to IIa fibres, while the proportion of slow twitch (I) fibres remains unchanged. However, sprint type (ballistic) training seems to have varying effects on muscle fibres; ranging from no effect whatsoever to conversion to IIa from both IIb and I fibres.

Most studies indicate that agonist EMG increases with heavy resistance and ballistic training as a result of an increase in motor unit recruitment or firing frequencies. However, it appears that firing frequency adaptation or even selective activation of fast twitch motor units, may be more critical during ballistic training. Antagonist coactivation decreases with heavy resistance training. In contrast, a high level of antagonist coactivation has been observed in sprinters. Notwithstanding the considerable body of literature devoted to the physiology of ballistic actions, and evaluation of training regimens directed at enhancing ballistic performance, there is still controversy over the optimum training method. The importance of specificity is generally accepted. The main issue is whether or not supplementary conventional heavy resistance training can also improve high speed performance.

The purpose of the present study was to evaluate the effectiveness of a supplementary heavy resistance exercise training program in promoting improvement in the performance of high velocity ballistic actions.

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CHAPTER II

THE ROLE OF HIGH RESISTANCE EXERCISE IN ENHANCING SPEED/POWER PERFORMANCE

ABSTRACT

Ten subjects were randomly assigned to train one arm with ballistic movements (BT), whereas the other arm trained with ballistic and heavy resistance movements (BT+HRT). The training program consisted of three training sessions per week, over a ten week period. The BT arm executed ten sets of six maximal ballistic elbow extension actions (10% MVC), whereas the BT+HRT arm executed five sets of six repetitions of maximal ballistic actions followed by five sets of five to eight repetitions of heavy resistance elbow extension actions. After training, evoked twitch contractile properties, ballistic, 1 RM, and isometric MVC measures were analyzed. Incorporated with all performance measures were EMG recordings of the agonist (AG) triceps and antagonist (ANT) biceps. Muscle biopsies of triceps were also taken to determine muscle fibre type composition, and fibre area.

The BT+HRT arm demonstrated a significant decrease in the percent population of type IIb fibres (22% to 18.8%). Furthermore, the BT+HRT arm produced hypertrophy, type IIa

(6184 to 7086 μm^2) and IIb (5714 to 6734 μm^2) fibre areas increased, whereas type I fibre areas (3503 to 3828 μm^2) did not significantly increase, after training. In contrast, the BT arm and control arm did not display fibre transformation or hypertrophy after training. Triceps evoked twitch peak torque increased for only the BT+HRT arm (12.5 to 13.8 N·m). Furthermore, the 1 RM increased significantly in the BT+HRT arm (~ 24%) but did not change significantly in the BT arm. However, ballistic and isometric MVC PT values increased similarly in both the BT (19.6 to 23.5 N·m; 45.4 to 52.6 N·m) and the BT+HRT (19.6 to 23.6 N·m; 49.6 to 56.0 N·m) arms.

The EMG results corresponded to the performance results in that triceps AEMG in the 1 RM test tended to increased more after HRT (0.71 to 1.01 mV) than only BT (0.72 to 0.81 mV), but in the ballistic (HRT= 0.63 to 0.79 mV; BT= 0.62 to 0.73 mV) and isometric MVC performance measures (HRT= 0.80 to 0.84 mV; BT= 0.80 to 0.87 mV), the AEMG results were similar.

Supplementary HRT caused muscle hypertrophy, particularly of the type II fibres, but did not promote improvement in ballistic performance with loads equal to or less than 10% of maximal isometric force.

1.0 INTRODUCTION

The improvement in athletic performance is the most obvious way for evaluating the effectiveness of various types of training programs. The development of an optimal training program requires numerous considerations. The most indisputable considerations may include the type of sport activity an athlete is involved in, the muscle groups to be exercised, the resistance (load) that should be used, the duration of training, the velocity of training, and the mode of training. With these factors taken into account, many coaches have developed effective sport specific training programs for athletes.

However, for a particular group of athletes, the development of an optimal training program is less clear. These athletes perform high velocity explosive movements against light loads (e.g., boxing and throwing). In these sports, the rate of force development may be more important than maximum force production (Wilson, 1992, cited in Young, 1993). Furthermore, it has been suggested that development of high velocity performance may be determined, to a substantial degree, by genetic endowment (Wilmore & Costill, 1994). Nevertheless, exercise physiologists, coaches, and athletes seek to create effective training systems to increase high velocity performance.

There is lack of agreement as to the optimum resistance training method for developing high speed force production, perhaps partly because training-induced increases in high velocity performance are more difficult to achieve as compared to slow velocity performance (Coyle et al., 1981). The main debate appears to be whether fast or "ballistic" training actions are more effective than slow high resistance actions, in improving high speed performance (Hedrick, 1993; Newton & Kraemer, 1994; Stone, 1993; Young, 1993).

Previous studies which have examined the effect of heavy resistance training on speed performance have been inconclusive (Delecluse et al., 1995; Sleivert et al., 1995 Whitley & Smith, 1966; Wilson et al., 1993). Whitley and Smith (1966) found that resistance training improved unloaded lateral swinging arm movement, whereas Sleivert et al. (1995) examined the effects of resistance and sprint training on a cycle ergometer power output test, and found that strength training had no influence on power performance. The transferability of heavy resistance training to high velocity actions may in part be due to the relative loads moved during the ballistic performance (% MVC).

With regards to strength training, the generally accepted specificity of velocity training principle dictates that for sport performance involving high speed ballistic actions against light loads, the most productive training method would consist of high speed ballistic actions with light loads (Caiozzo et al., 1981; Coyle et al., 1981; Kanehisa & Miyashita, 1983). However, this method precludes a potentially valuable adaptation, since it is well known that skeletal muscle adapts to heavy resistance training by becoming larger and that this increase in muscle size is due to a greater degree of hypertrophy of the fast twitch (FT) fibres (MacDougall et al., 1979). This adaptation may serve to increase force and thus acceleration at the start of a ballistic action, and would be unlikely to occur following ballistic training using light loads because high force production is necessary as a stimulus to hypertrophy. However, other intramuscular changes resulting from hypertrophy may be counter-productive. For example, hypertrophy may alter the angle of fibre pennation in a way that reduces muscle shortening velocity (Tsunoda et al., 1993). Thus, the possibility that supplementary high resistance training may obstruct rather than augment high velocity performance, cannot be excluded.

Therefore, the purpose of the present study was to evaluate the effectiveness of a supplementary heavy resistance exercise training program in promoting improvement in the performance of high velocity ballistic actions. The results of the study will have important implications for the design of training programs for athletes.

2.0 METHODS

2.0.1 Subjects and Design

Twenty male university students, with a background of regular physical activity, were recruited for the study (see Table 1). None of the subjects were elite athletes or had engaged in weight training or other forms of strength training for at least one year. Ten of the subjects were selected at random and formed the training group. The subjects in the training group were randomly assigned to train one arm with ballistic movements, whereas the other arm trained with ballistic and heavy resistance movements. The remaining ten subjects formed the non-training control group. All subjects were tested pre- and post-training in all measurements. Subjects gave their informed written consent and the study carried the approval of McMaster University Human Ethics Committee.

One subject in the training group failed to complete the training program due to a hand injury unrelated to the experiment. Therefore, data were collected and analyzed for only 9 trained subjects.

Table 1. Physical characteristics of subjects pre- and post-testing. Values are means ± SE

			MASS (kg)	
GROUP	HEIGHT (cm)	AGE (y)	PRE	POST
TRAINED	180.3 ± 1.6	20.2 ± 0.2	76.1 ± 2.8	77.1 ± 2.2
CONTROL	179.7 ± 1.7	21.2 ± 0.6	73.3 ± 2.2	74.1 ± 2.1

2.0.2 Apparatus

Ballistic training (BT) and testing was performed using a custom-made apparatus. Subjects sat in an adjustable chair with their upper arm resting on a horizontal support plate, and their semi-supinated forearm strapped to a arm manipulandum. The forearm was secured to the arm manipulandum by velcro straps to prevent extraneous movements during elbow extension actions. The arm manipulandum was mounted on a steel rotatory axis which allowed for elbow rotation. An aluminum alloy wheel was centred and fixed to the free end of the axis with an adjustable weight stack fastened to it via a nylon rope. Torque and displacement potentiometers were positioned on the apparatus, the signals from which were amplified and fed into a 12 bit A/D converter (Dataq Electronics) and then into IBM personal computer. The signals were sampled at 1250 Hz and Codas data acquisition software (Dataq Electronics) was used to process the data.

The chair was adjusted so that the flexed upper arm of the subject was positioned at a shoulder joint angle of ~ 90° flexion. The forearm was perpendicular to the horizontal plane; thus, the starting elbow joint angle was ~ 90°. Subjects performed isolated concentric ballistic elbow extensions, with the intent to continue the movement to full extension; however, a large soft pad stopped the movement prior to full extension. In addition, all subjects were instructed to perform ballistic elbow extensions as forcefully and rapidly as possible.

A companion apparatus allowed elbow extensions to be performed against high resistance. This apparatus consisted of a single pulley rope system mounted to a wall, with an adjustable weight stack, and a table and chair in front of the pulley system. Subjects were seated in the chair with their upper arm supported on the table. The subject's shoulder and elbow starting joint angles and forearm position were identical to the ballistic training condition. Subjects were instructed to grasp a rope attached to the pulley system and perform a concentric elbow extension action (from 90° to full extension) followed by an eccentric action back to the starting position. Each action lasted ~ 2.5 s. A strain gauge and displacement potentiometer were fastened to the apparatus so that torque and displacement could be measured.

Both the ballistic and heavy resistance devices were calibrated before pre- and post-testing to ensure valid measurements.

2.0.3 Training Protocol

The training program consisted of three training sessions per week, with one day of rest between sessions, over a ten week period. The ballistic training (BT) arm executed ten sets of six maximal ballistic elbow extension actions, whereas the ballistic plus the supplementary heavy resistance training (BT+HRT) arm executed five sets of six repetitions of maximal ballistic actions followed by five sets of five to eight repetitions of heavy resistance elbow extension actions. Two to three minute rest periods were given between sets and 15 s were allocated between ballistic repetitions (actions). Ballistic actions were performed against a load corresponding to 10% of pre-training maximum isometric force (MVC). The 10% load was not altered during training despite any changes in maximum MVC. This was done in order to keep the absolute criterion "target" load at the same level throughout the study. However, the heavy resistance load was increased when the subject achieved the upper limit (8) of the repetition range in all sets in two consecutive training sessions. Ballistic training of both arms was completed prior to supplementary heavy resistance training. Subjects who missed a training session were obliged to make it up the following day.

2.0.4 Testing and Measurements

Prior to testing, all subjects were familiarized with all movements and with electrical stimulation. During the familiarization session each subject was properly positioned and electrically stimulated eight to twelve times, and performed all test movements four to eight times. Pre-testing began and finished prior to training and the post-testing began four to six days after the ten week training period (Table 2). Testing was conducted for both arms of the training group while the control group was only tested in one arm (randomly selected). The measures which were made using the ballistic apparatus included: evoked twitch contractile properties, isometric MVC, and ballistic performance. The 1 RM performance measure was assessed on the heavy resistance training apparatus. All subjects were allowed a three to five min rest before the start of each separate performance test. Incorporated with all performance measures were EMG recordings of the agonist (AG) triceps and antagonist (ANT) biceps. Muscle biopsies of long head triceps were also taken to determine muscle fibre type composition, and fibre area.

Table 2. The order of the pre- and post-tests for the trained and control groups.

	Day 1 (One arm)	Day 2 (Second arm)	Day 3 (Both arms)	Day 4 (Both arms)
Trained Group	Evoked twitch test Isometric MVC test Ballistic test	Evoked twitch test Isometric MVC test Ballistic test	1 RM test	Muscle biopsy

	Day 1 (One arm)	Day 2 (One arm)	Day 3 (One arm)
Control Group	Evoked twitch test Isometric MVC test Ballistic test	1 RM test	Muscle biopsy

Evoked Isometric Twitch Contractile Properties

Twitch contractions were evoked by percutaneous electrical stimulation. Skin preparation consisted of abrading the skin around the triceps followed by cleaning the skin surface with an antiseptic isopropyl alcohol pad. The stimulating electrodes were two large lead plates wrapped in moistened gauze impregnated with conducting cream. The cathode (80 mm x 40 mm) electrode was placed over the lateral and long heads of the triceps ~ 17 cm proximal to the olecranon. The smaller anode (55 x 40 mm) was positioned on the triceps tendon ~ 6 cm proximal to the olecranon.

Subjects were electrically stimulated with a fixed shoulder joint angle of 80° flexion and a fixed elbow joint angle of 135° flexion (0°= full extension). Single rectangular voltage pulses (55 μs) were delivered from a high-voltage Grass S11 stimulator. The stimulus was increased by 10% above the voltage that yielded a maximal twitch to ensure maximal activation. Maximal twitch responses were then analyzed with a modified computer software program. Measurements included: peak torque (PT), time to peak torque (TPT), maximum rate of torque development (MRTD), maximum rate of torque relaxation (MRTR), torque-time integral (TTI), TTI to 1/2 relaxation time (TTI 1/2 R) and 1/2 relaxation time (1/2 R).

Isometric MVC

For the MVC measurement, subjects sat in the ballistic apparatus with their forearm supported and secured by the arm manipulandum at a locked elbow joint angle of 90°. Subjects where instructed to perform two to three MVCs as rapidly and forcefully as possible, each lasting for ~ five seconds. Subjects were allowed to recover for two min between MVCs. The MVC producing the greatest peak torque was selected for analysis. PT and MRTD of the MVC were determined. Further analysis consisted of dividing the MVC into six half second intervals, starting at the onset of agonist activation (first interval included an ~ 20 ms, electromechanical delay), in order to determine and average torque and average integrated electromyography activity (AEMG) for each interval.

Ballistic Performance

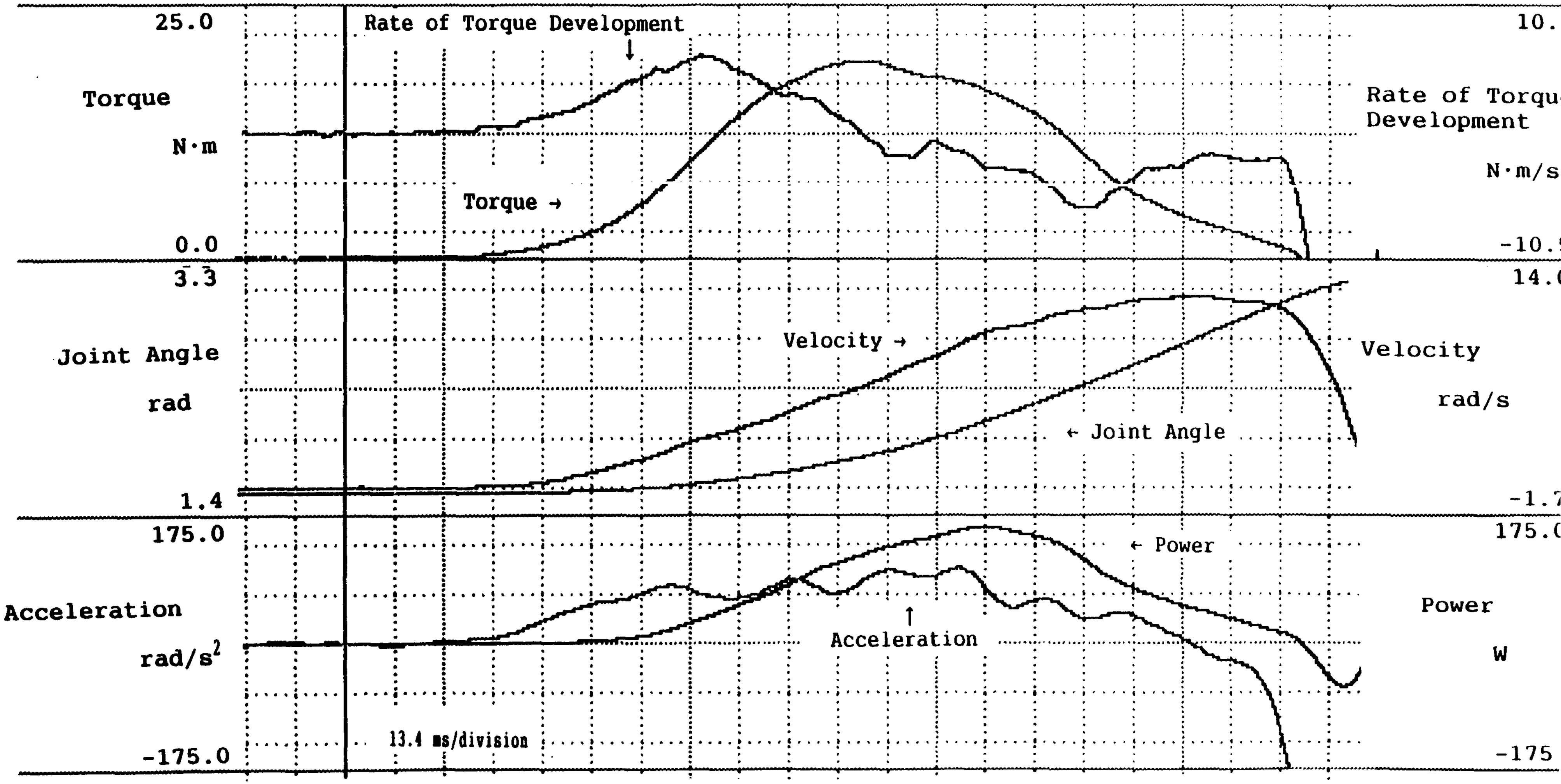
The MVC measurement was performed initially to determine the ballistic movement load (10% of MVC). This load was then set for the ballistic extension trials. Arm positioning for the ballistic action test was identical to training. Subjects extended their elbow from an initial angle of ~ 90° to full extension (driving the hand into a large pad). Subjects were instructed to move on their own cue, as rapidly and forcefully as possible, and to remain in the fully extended position for

~ one second before they returned their forearm to the starting position. Subjects were allowed 30 to 40 s rest after each trial. The subjects performed six maximal ballistic elbow extension movements. The three ballistic actions with the highest peak torques were selected and averaged for analysis. Measurements were made of PT, TPT, movement time (MT), MRTD, peak velocity (PV), peak acceleration (PA), peak power (PP) (Figure 1), agonist and antagonist AEMG (see below), and antagonist/agonist coactivation ratios.

1 RM Performance

All subjects performed the 1 RM test on the heavy resistance apparatus. The body and arm positioning for each subject was identical to the heavy resistance training. Subjects lifted a progressively greater weight on each trial until their 1 RM was reached. Subjects were instructed to extend in a smooth motion and not to move any other body parts in an effort to assist the elbow extension. Subjects were given a two to three min rest period between trials. Typically, subjects reached their 1 RM in no more than five trials.

Figure 1. The figure displays a tracing of torque and rate of torque development (top), velocity and joint displacement (middle), and acceleration and power (bottom) during a typical ballistic action.


25.0
Rate of Torque Development
10.
Torque
N·m
Rate of Torqu
Development
N·m/s
Torque →
0.0
-10.
3.3
14.
Joint Angle
rad
Velocity →
Velocity
rad/s
← Joint Angle
1.4
-1.
175.0
175.
← Power
Acceleration
rad/s²
Power
W
Acceleration
13.4 ms/division
-175.0
-175

EMG Measurements

Prior to applying the recording electrodes, the skin surface over the triceps and biceps of the appropriate arm was abraded with sand paper and cleaned with an antiseptic isopropyl alcohol pad. EMG signals were recorded using four mm Ag-Ag/Cl bipolar surface electrodes, with an interelectrode distance of 25 mm. The electrode positions were determined while the subject contracted isometrically. For the triceps muscle, the electrodes were positioned ~ 16 cm above the olecranon process. For the biceps muscle, the electrodes were placed over the centre of the muscle belly, while the ground electrode was positioned on the forearm (anterior surface, 18 cm below the olecranon process). Measurements were made of maximal agonist and antagonist AEMG activity (all EMG recordings were rectified, integrated, and averaged over the entire ballistic and 1 RM movement and for 0.5 s intervals for the MVC), and co-activation ratios were calculated for analysis during MVC, ballistic and 1 RM performance tests.

Muscle Biopsies

Pre- and post-training biopsies were taken following all other pre-and post-training tests. The training group had biopsy samples taken from both arms, while the control group had one biopsy taken from one arm.

Needle biopsy samples were extracted from the long head of triceps and prepared for routine histochemical analysis. The muscle sample was removed from the needle, cross-sectionally mounted in tragacanth gum, immediately frozen in isopentane and cooled by liquid nitrogen to ~ -160°C, and stored at -70°C. After all post-testing, the samples were thawed to -20°C and serially sectioned (12 μm thick) in a cryostat for histochemical staining. Sections were stained for myofibrillar adenosine triphosphatase activity at preincubation pH values of 4.3, 4.6, and 10.4 (Staron et al., 1991). Tissue sections were photographed under the light microscope and projected slide were made in order to determine fibre type distribution and fibre areas. Cross-sectional areas of 100 fibres of each type (type I, IIa, and IIb) were measured with the use of a custom-made computerized digitizer. The total number of fibres counted for the BT and BT+HRT arm were 1211 ± 160 and 1107 ± 91, pre-, and 1127 ± 140 and 1104 ± 97 post-testing, respectively. The total number of fibres counted for the control group was 1218 ± 105 and 1006 ± 114, pre- and post-testing, respectively.

2.0.5 Statistical Analysis

Ordinary statistical methods were used to calculate means, standard deviations, and standard errors of the mean.

A two factor within subject ANOVA, with repeated measures for arm (BT, BT+HRT arm) and time (pre-, post-training) was used to analyze the results in the training group. A one factor (time) repeated measure ANOVA was used to analyze the results in the control group. Post hoc analysis of mean values was performed using Tukey's method. The probability level for statistical significance was accepted at $P \leq 0.05$.

3.0 RESULTS

The subjects' physical characteristics are shown in Table 1. There were no significant differences between groups, although the training group was slightly taller and heavier. The training group's compliance to training was 100 %.

Ballistic Performance. There was no arm x time interaction (BT vs. BT+HRT arms) for any ballistic measure, which indicated that supplementary heavy resistance training had no effect on ballistic performance, beyond that achieved by ballistic training alone. Performance measures are shown in Table 3.

In three measures (PT, MT, PA), there were significant changes (over time) in the trained group, whereas the control group did not show any significant changes (Figures 2-4). PT, MT and PA for the trained group (collapsed across arm) increased from 19.6 to 23.5 N·m, (~ 20%), decreased from 206 to 198 ms (~ 4%), and increased from 121.5 to 134.6 rad·s^{-2} (~ 11%), respectively. In the remaining measures (MRTD, TPT, PV, and PP) significant increases (over time) were found in both groups. (Figures 5-6). The MRTD increased from 448.6 to

Table 3. The ballistic performance measures for the ballistic (BT), ballistic and heavy resistance(BT+HRT) and control (CON) arms. The (*) symbol indicates a main effect for time. The (†) symbol indicates a relative (percent) difference compared to the CON arm ($P \leq 0.05$). Values are means ± SE.

	PT (N·m)	MRTD (N·m/s)	TPT (ms)	MT (ms)	PV (rad/s)	PA (rad/s^2)	PP (W)
BT ARM							
PRE	19.6	448.3	86.1	199.8	13.2	122.1	153.9
	±0.9	±26.8	±3.3	±4.6	±0.4	±5.7	±10.1
POST	23.5*	685.2*†	78.1*	194.8*	13.5*	133.1*	185.9*
	±0.9	±34.7	±3.0	±8.5	±0.3	±4.6	±10.2
% Diff.	**19.9**	**52.8**	**-9.3**	**-2.5**	**2.3**	**9.0**	**20.8**
BT+HRT ARM							
PRE	19.6	448.9	97.6	211.4	13.1	120.9	157.9
	±1.0	±46.3	±5.9	±6.5	±0.4	±3.4	±6.8
POST	23.6*	684.4*†	82.8*	201.9*	13.9*	136.2*	205.2*†
	±0.9	±48.0	±3.4	±5.3	±0.4	±5.8	±11.4
% Diff.	**20.4**	**52.5**	**-15.1**	**-4.5**	**6.1**	**12.7**	**30.0**
CON ARM							
PRE	17.1	330.3	125.1	246.0	12.1	111.3	130.3
	±0.8	±19.0	±7.0	±8.0	±0.3	±3.5	±7.9
POST	17.6	406.8*	111.1*	240.9	12.4*	113.3	139.6*
	±0.8	±31.2	±5.6	±5.8	±0.3	±3.8	±7.8
% Diff.	**2.9**	**23.1**	**-11.2**	**-2.1**	**2.5**	**1.8**	**7.4**

Figure 2. Ballistic peak torque in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(□) and post-testing(■). * significant increase pre- to post-training (P≤0.01). Values are means ± SE.

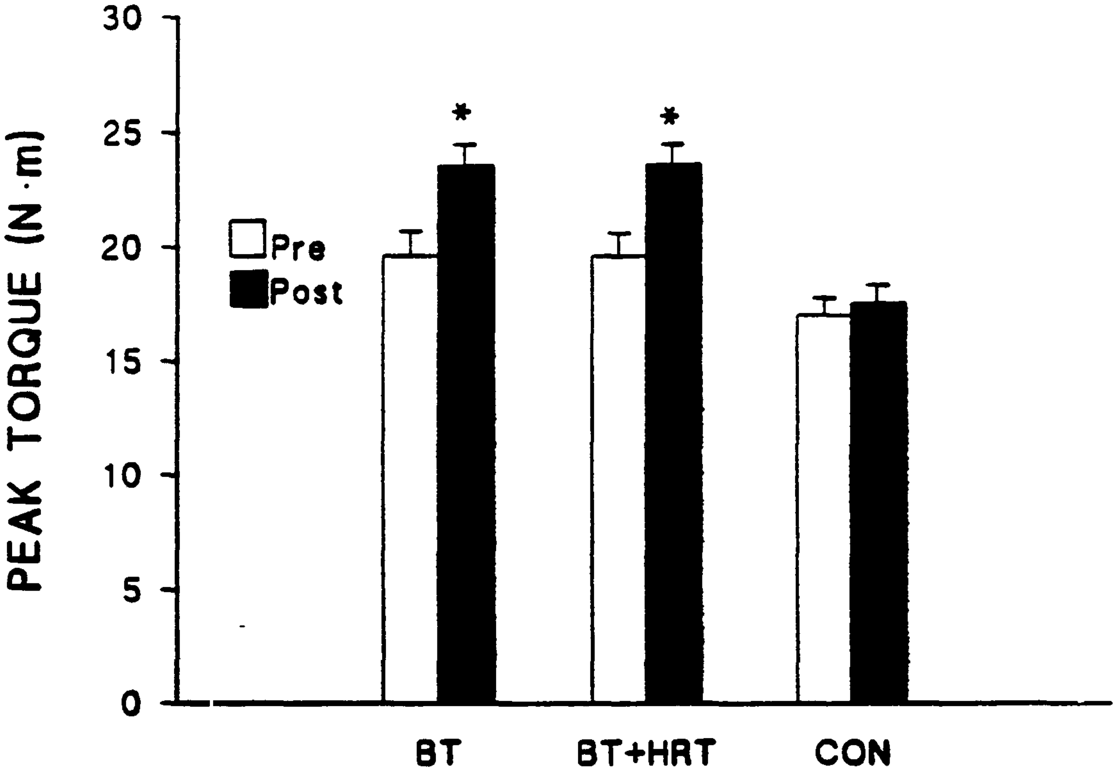

PEAK TORQUE (N·m)
30
25
20
15
10
5
0
Pre
Post
*
*
BT
BT+HRT
CON

Figure 3. Ballistic movement time (MT, in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre- (☐) and post-testing (■). * significant decrease pre- to post-training ($P \leq 0.05$). Values are means ± SE.

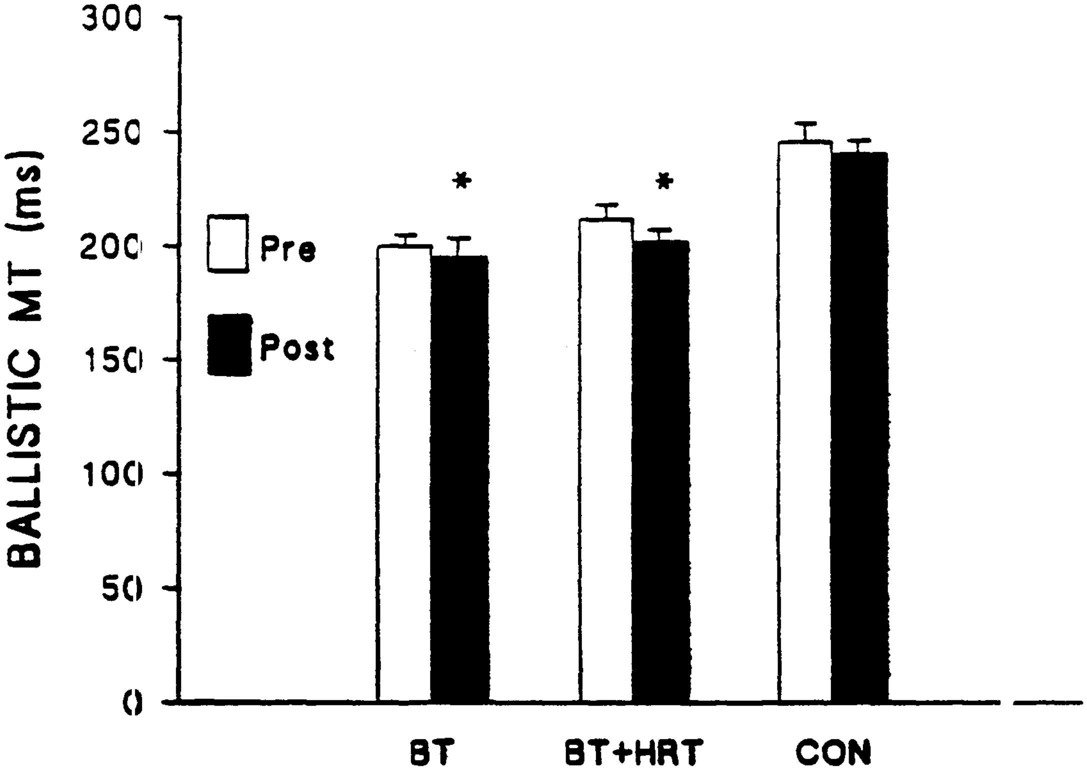

BALLISTIC MT (ms)
300
250
200
150
100
50
0
Pre
Post
*
*
BT
BT+HRT
CON

Figure 4. Ballistic peak acceleration (PA), in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(☐) and post-testing(■). * significant increase pre- to post-training ($P \leq 0.01$). Values are means ± SE.

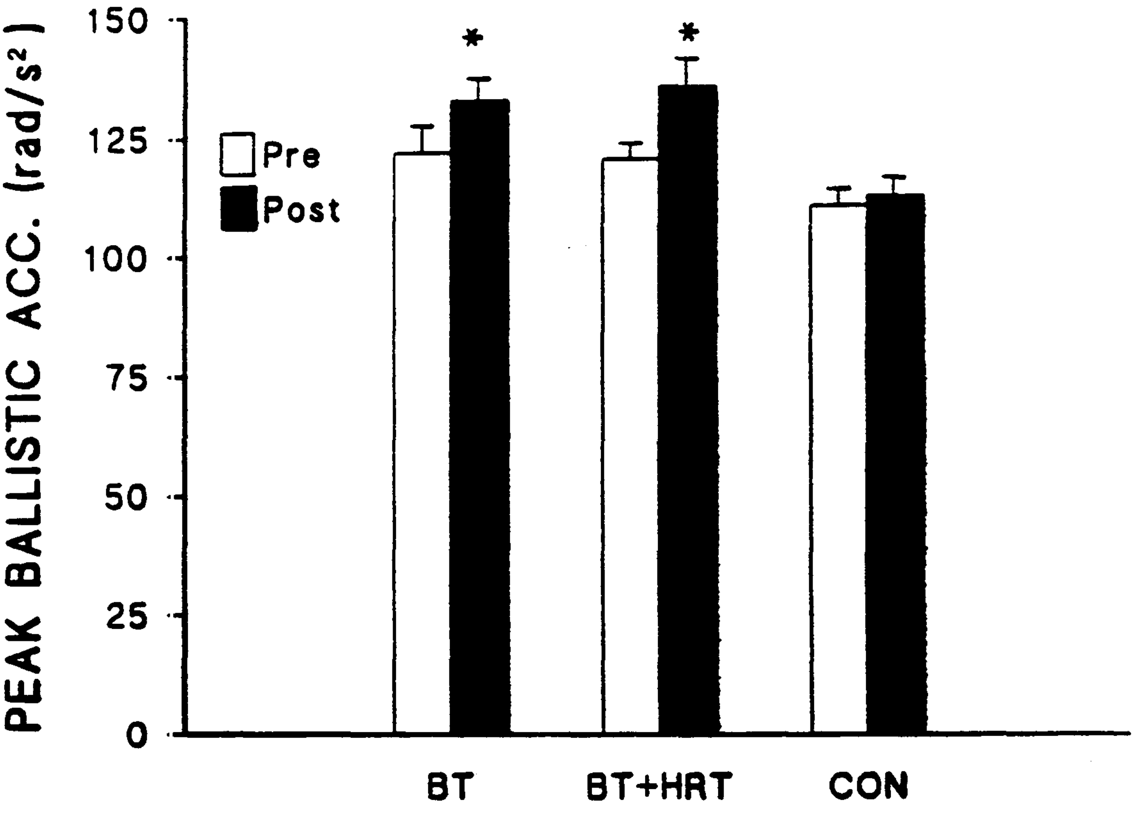
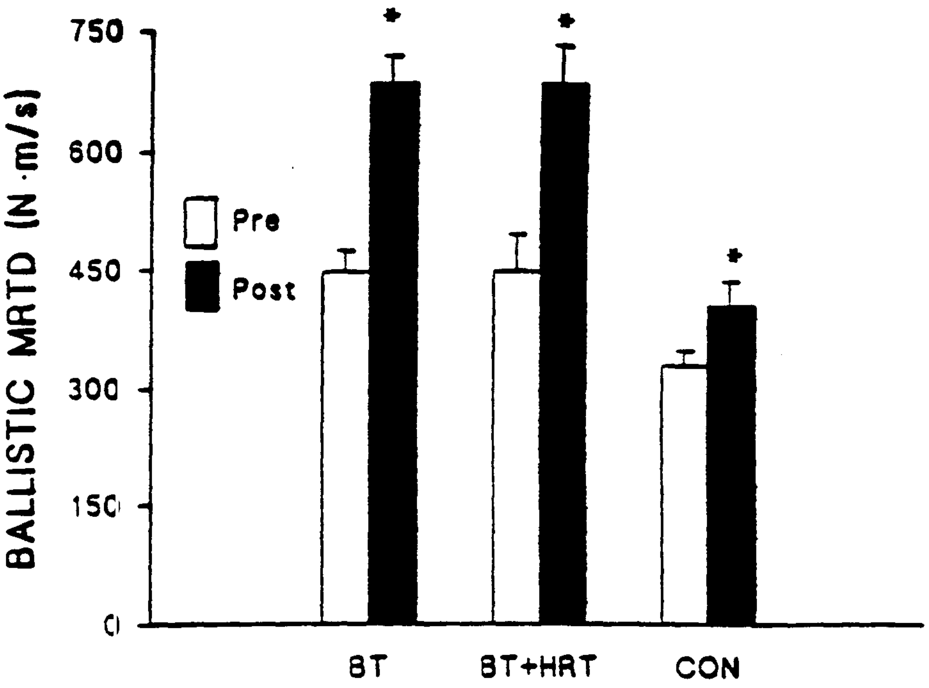

PEAK BALLISTIC ACC. (rad/s²)
150
125
100
75
50
25
0
Pre
Post
*
*
BT
BT+HRT
CON

Figure 5. Ballistic rate of torque development (MRTD, top), and time to peak torque (TPT, bottom) in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(□) and post-testing(■). * significant increase in MRTD and a significant decrease in TPT pre- to post-training ($P \leq 0.01$). Values are means ± SE.


BALLISTIC MRTD (N·m/s)
750
600
450
300
150
0
Pre
Post
*
*
*
BT
BT+HRT
CON

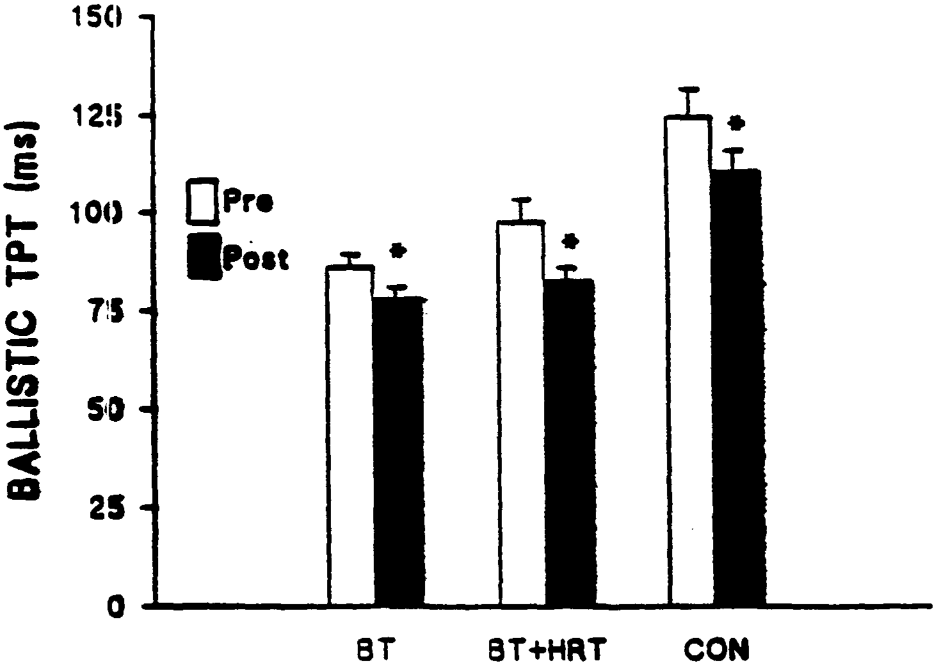
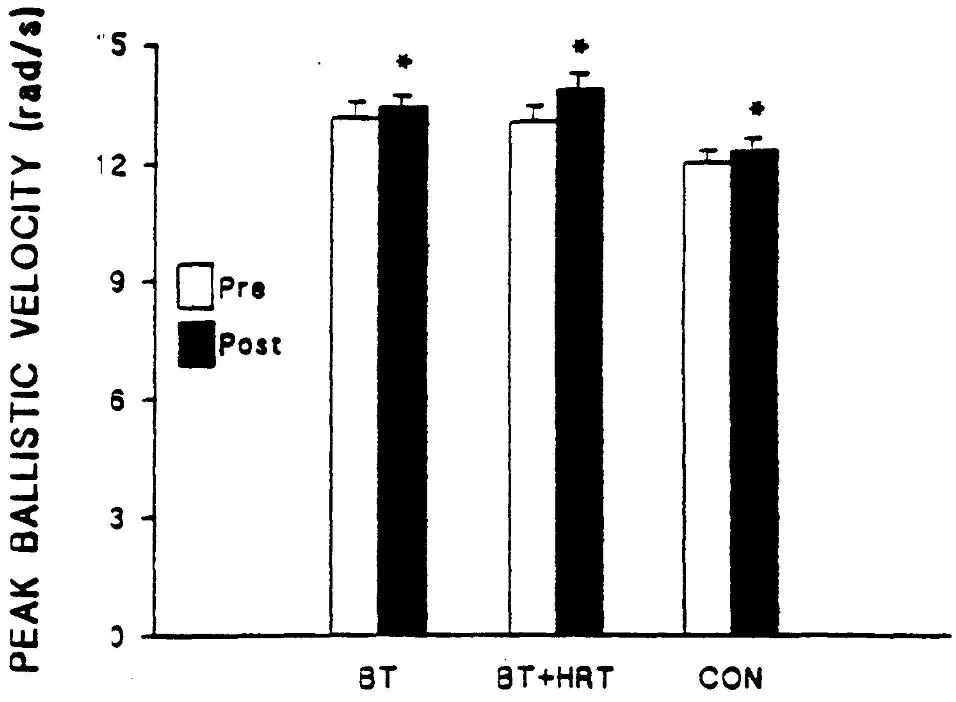
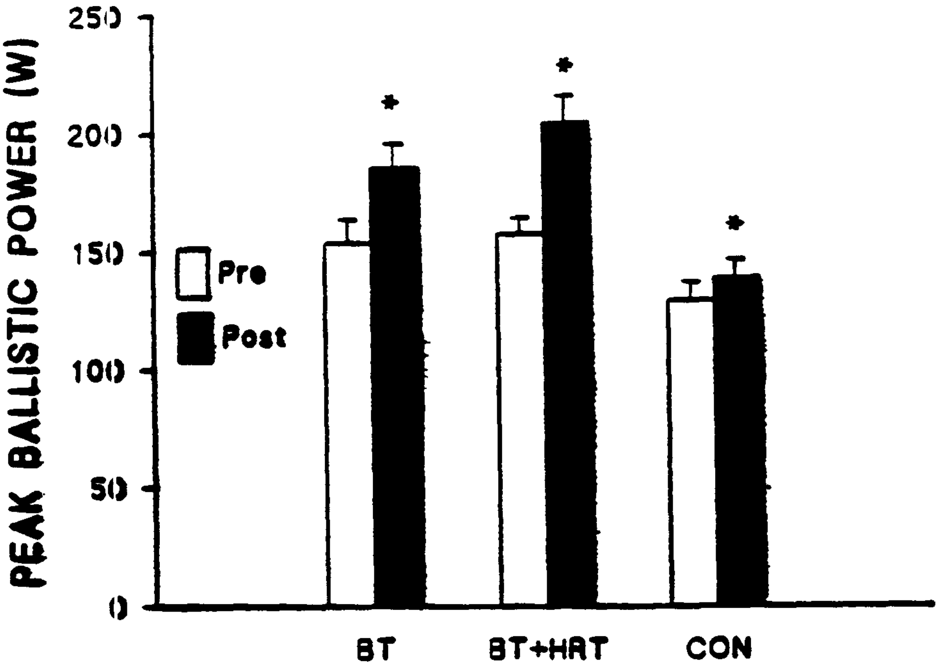

BALLISTIC TPT (ms)
150
125
100
75
50
25
0
Pre
Post
*
*
*
BT
BT+HRT
CON

Figure 6. Ballistic peak velocity (PV, top), and peak power (PP, bottom) in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(□) and post-testing(■). * significant increase pre- to post-training ($P \leq 0.01$). Values are means ± SE.


PEAK BALLISTIC VELOCITY (rad/s)
15
12
9
6
3
0
Pre
Post
*
*
*
BT
BT+HRT
CON


PEAK BALLISTIC POWER (W)
250
200
150
100
50
0
Pre
Post
*
*
*
BT
BT+HRT
CON

684.8 N·m·s^{-1} (~ 53%) and from 330.3 to 406.8 N·m·s^{-1} (~ 23%); TPT decreased from 92 to 80 ms (~ 13%) and from 125.0 to 111.1 ms, (~ 12%); PV increased from 13.1 to 13.7 rad·s^{-1} (~ 4%) and from 12.1 to 12.4 rad·s^{-1} (~ 2%); PP increased from 155.9 to 195.5 W (~ 25%) and from 130.3 to 139.6 W (~ 7%) for the trained and control groups, respectively, pre- to post-testing. Further analysis using a one factor (arm) ANOVA, revealed relative (percent) differences (pre- to post-training) between training and control arms. MRTD was significantly greater in the trained arms compared to the control arm. Moreover, PP was significantly greater in the BT+HRT compared to the control arm (Table 3).

1 RM Performance. 1 RM increased significantly in the BT+HRT arm (~ 24%) but did not change in the BT arm nor the control group (arm x time interaction, P< 0.01, Figure 7).

Isometric MVC. There was no arm x time interaction (BT vs. BT+HRT arms) for any MVC measure, which indicated that both ballistic and heavy resistance training had similar effects on MVC.

Peak and average torque results are illustrated in Figure 8. Peak torque for the BT and BT+HRT arm increased from 45.4 to 52.6 N·m (~ 16%) and 49.6 to 56.0 N·m (~ 13%),

Figure 7. The 1 RM in ballistic (BT), ballistic and heavy resistance (BT+HRT), and control arms pre-(□) and post-testing(■). * significant increase pre- to post-training ($P \leq 0.01$). Values are means ± SE.

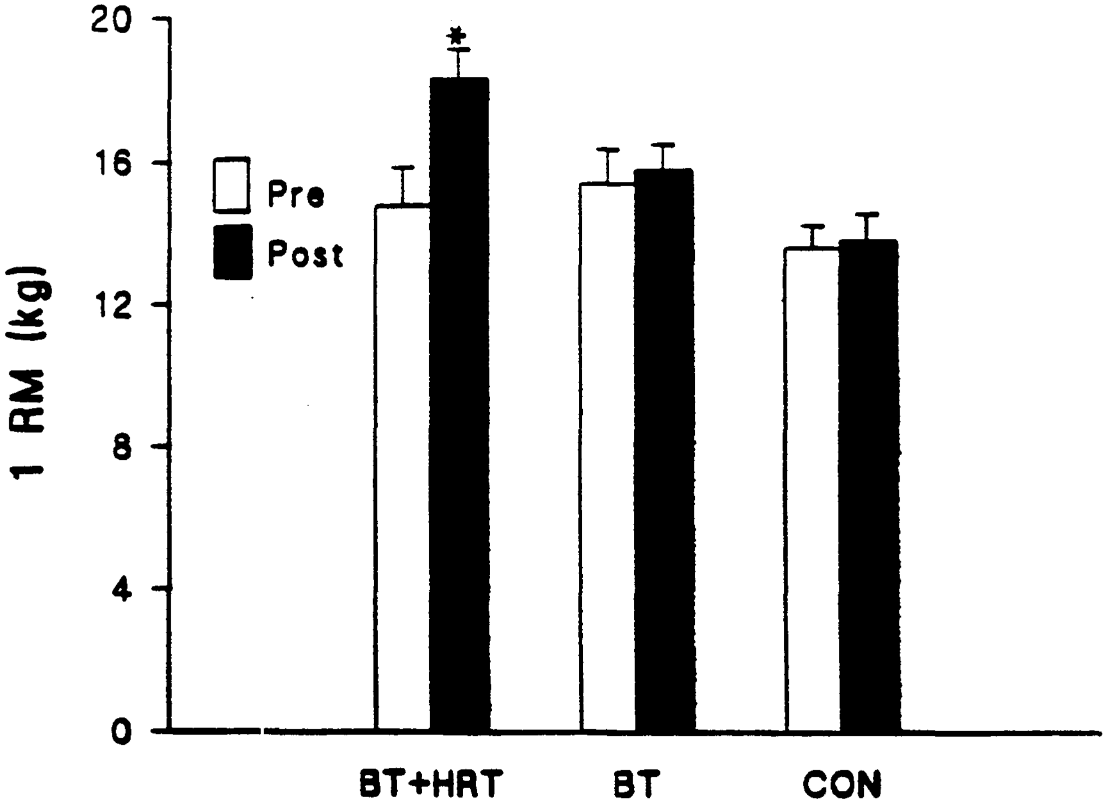
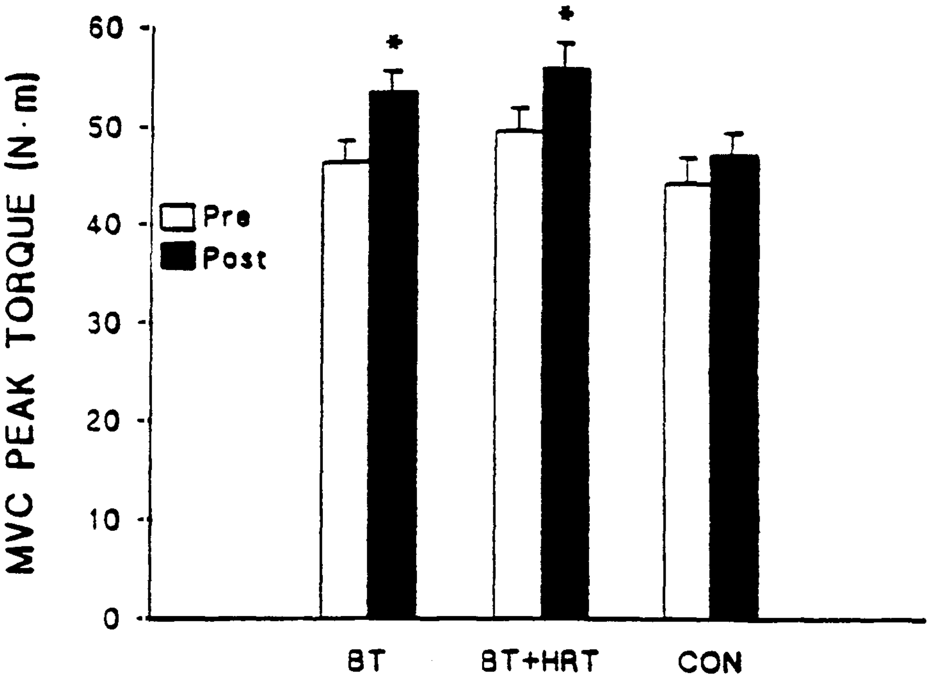
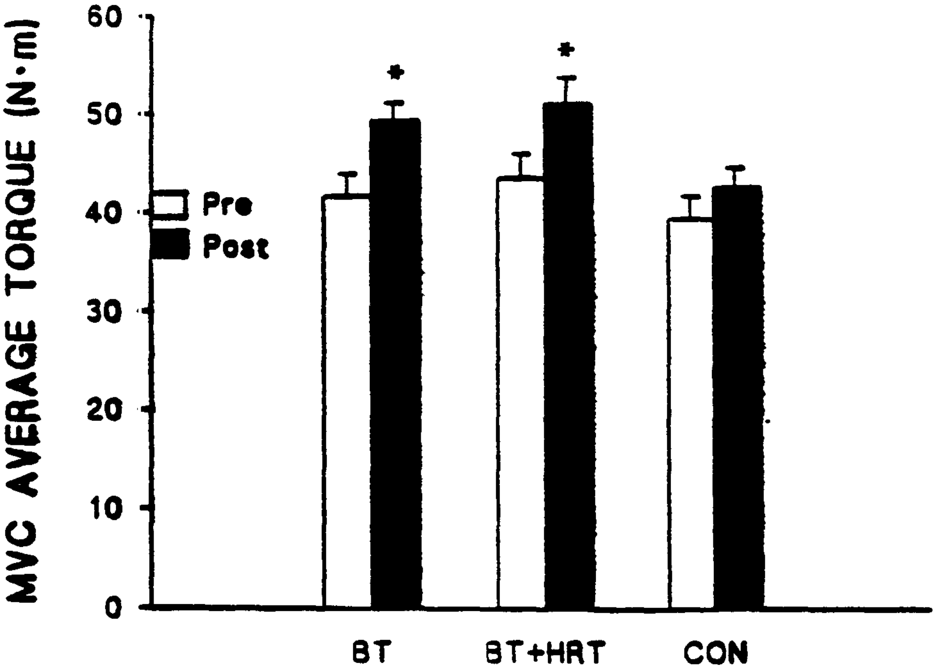

20
16
12
8
4
0
1 RM (kg)
Pre
Post
*
BT+HRT
BT
CON

Figure 8. Isometric MVC peak torque (top), and average torque (bottom) in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(☐) and post-testing(■). * significant increase pre- to post-training ($P \leq 0.01$). Values are means ± SE.


MVC PEAK TORQUE (N·m)
60
50
40
30
20
10
0
□ Pre
■ Post
*
*
BT
BT+HRT
CON


MVC AVERAGE TORQUE (N·m)
60
50
40
30
20
10
0
□ Pre
■ Post
*
*
BT
BT+HRT
CON

respectively, whereas the peak torque did not change significantly in the control group (44.5 to 47.4 N·m). Average torque values, collapsed across time intervals for the BT and BT+HRT arm, significantly increased by 18.0% and 17.0% (41.9 to 49.5 N·m; 43.7 to 51.3 N·m). In contrast, average torque for the control group did not change significantly after training (39.7 to 43.0 N·m).

Figure 9 shows a significant increase in MVC MRTD in the training group. MRTD for the BT and BT+HRT arm changed from 491.6 to 653.1 N·m·s^{-1} (~ 33%) and 476.5 to 586.3 N·m·s^{-1} (~ 23%) pre- to post-testing. In contrast, the control group did not display a significant change (422.1 to 402.6 N·m·s^{-1}).

Evoked Twitch Contractile Properties. The results are shown in Table 4. A two factor within subject ANOVA, with repeated measures for time (pre-, post-training) did not reveal any significant differences for arm or time, but several trends were found. Therefore, a one factor ANOVA with a repeated measure for time was used for individual training arms. The BT+HRT arm showed significant increases in PT, MRTD and MRTR of 10.4, 16.2, and 29.7%, respectively (Figure 10). The BT arm and control group did not display any significant differences for any measures.

Figure 9. Isometric MVC maximum rate of torque development (MRTD) in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(☐) and post-testing(■). * significant increase pre- to post-training ($P \leq 0.01$). Values are means ± SE.

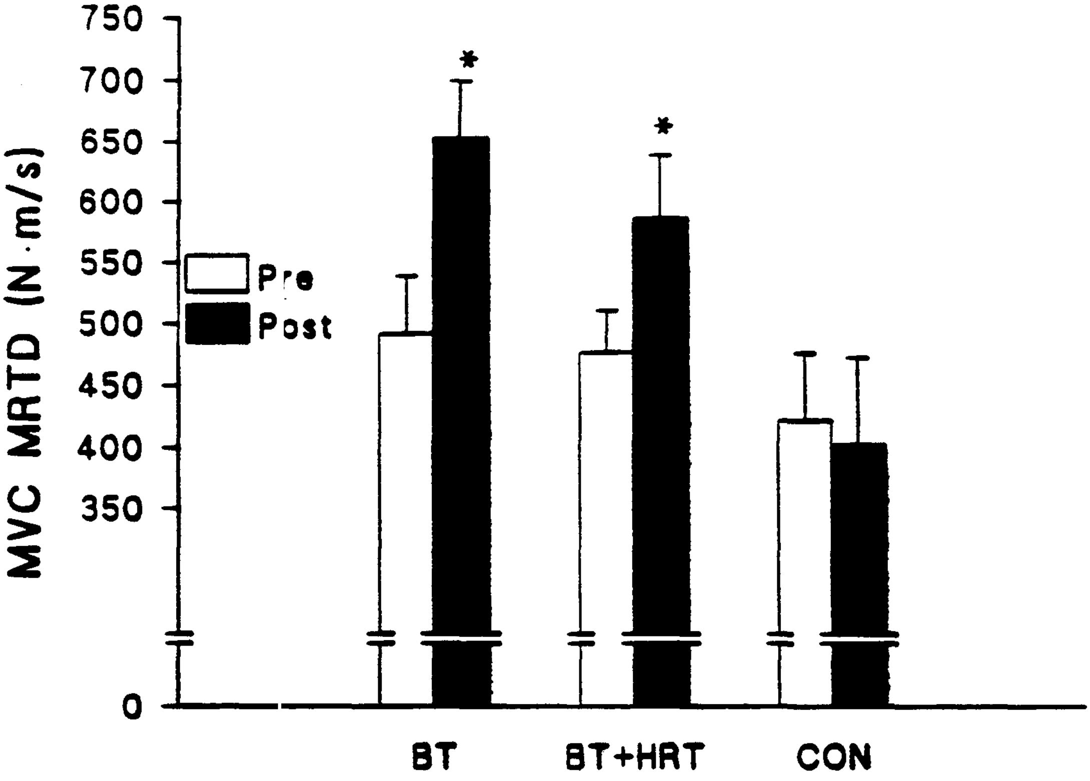
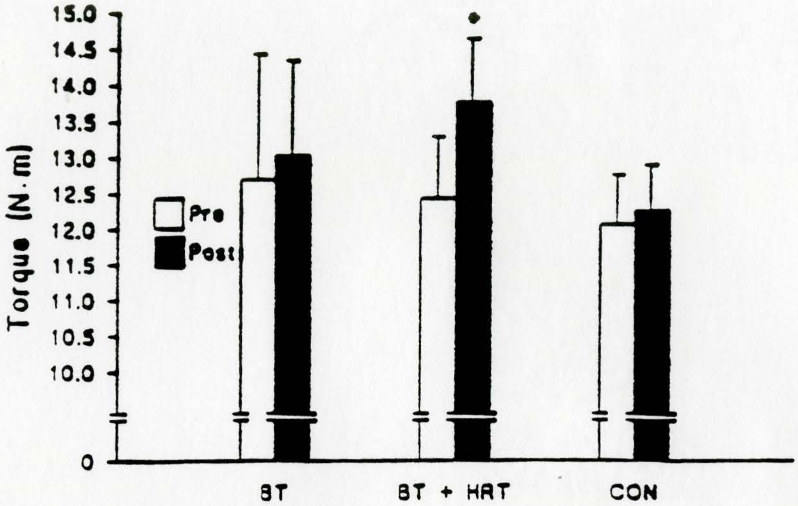
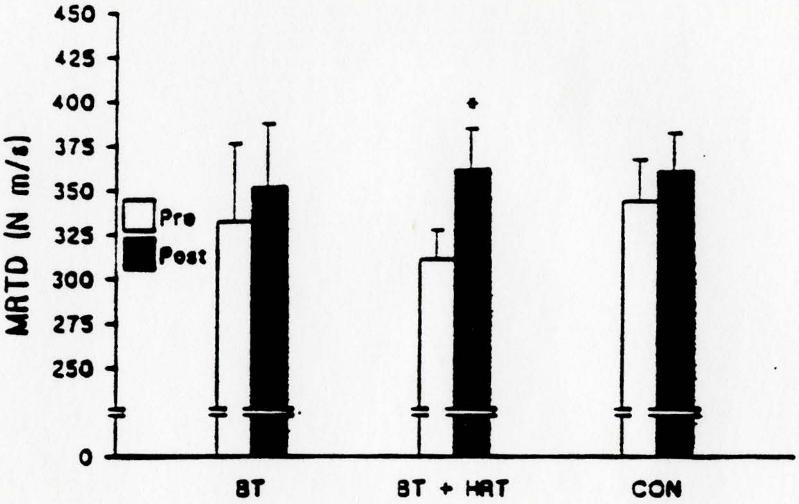

MVC MRTD (N·m/s)
750
700
650
600
550
500
450
400
350
0
Pre
Post
*
*
BT
BT+HRT
CON

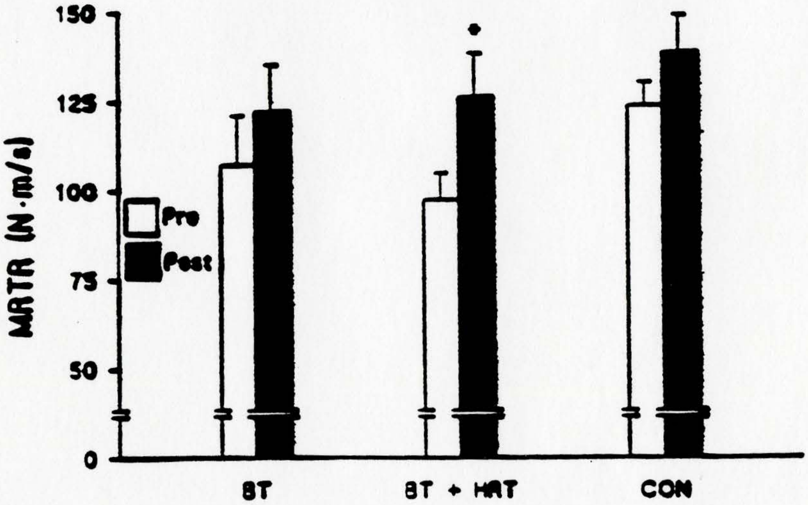
Table 4. The contractile properties of the ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre- and post-testing. The (*) symbol indicates a main effect for time (P≤0.05). Values are means ± SE

		PT (N·m)	TPT (ms)	MRTD (N·m/s)	MRTR (N·m/s)	TTI (N·m·s)	TTI 1/2 R (N·m·s)	1/2 R (ms)
BT ARM								
	PRE	12.8	59.7	332.3	-107.4	1.8	1.23	85.0
		±1.7	±1.3	±43.9	±13.8	±0.3	±0.2	±5.2
	POST	13.0	61.7	351.6	-122.5	1.9	1.33	81.5
		±1.3	±1.6	±35.7	±13.0	±0.2	±0.2	±3.8
	% Diff.	**1.6**	**3.4**	**5.8**	**14.1**	**5.6**	**8.3**	**-4.1**
BT+HRT ARM								
	PRE	12.5	62.7	311.0	-97.5	1.9	1.31	89.9
		±0.9	±0.9	±16.5	±7.5	±0.2	±0.1	±5.2
	POST	13.8*	62.9	361.4*	-126.5*	2.1	1.44	88.4
		±0.9	±1.9	±23.1	±12.2	±0.2	±0.1	±4.0
	% Diff.	**10.4**	**0.3**	**16.2**	**29.7**	**10.5**	**7.8**	**-1.7**
CON ARM								
	PRE	12.1	60.5	334.0	-124.1	1.6	1.16	74.2
		±0.7	±1.7	±23.3	±6.6	±0.1	±0.1	±3.9
	POST	12.3	61.7	361.1	-139.0	1.6	1.18	69.4
		±0.6	±1.1	±21.8	±10.5	±0.1	±0.1	±3.4
	% Diff.	**1.7**	**2.0**	**8.1**	**12.0**	**0.0**	**0.0**	**-6.5**

Figure 10. Evoked twitch contractile properties for twitch peak torque (PT,top), maximum rate of torque development (MRTD, middle), and maximum rate of torque relaxation (MRTR, bottom) in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(☐) and post-testing(■). * significant increase pre- to post-training ($P \leq 0.05$). Values are means ± SE.


Torque (N.m)
15.0
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0
10.5
10.0
0
Pre
Post
*
BT
BT + HRT
CON


MRTD (N m/s)
450
425
400
375
350
325
300
275
250
0
Pre
Post
*
BT
BT + HRT
CON


MRTR (N·m/s)
150
125
100
75
50
0
Pre
Post
*
BT
BT + HRT
CON

Ballistic AEMG. Ballistic AEMG results are shown in Table 5 and Figure 11. A time main effect for both AG and ANT AEMG was found. AG and ANT AEMG for the trained group (collapsed across arm) increased from 0.63 to 0.76 mV (21%), and from 0.09 to 0.11 mV (22%), respectively. In contrast, AG and ANT AEMG for the control group did not change significantly.

The ANT/AG coactivation ratios did not change pre- to post-testing for the trained or the control group (Table 5).

1 RM AEMG. 1 RM AEMG results are shown in Table 5. AG and ANT AEMG activation did not change significantly pre- to post-testing for either group. However, there was a trend; AG AEMG for the trained arms combined increased from 0.72 to 0.92 mV (28%, P=0.054), and the control group decreased from 0.74 to 0.65 mV (Figure 12). Further analysis using a one factor (arm) ANOVA indicated that the BT+HRT arm possessed a greater relative (percent) differences (pre- to post-training) compared to the control arm.

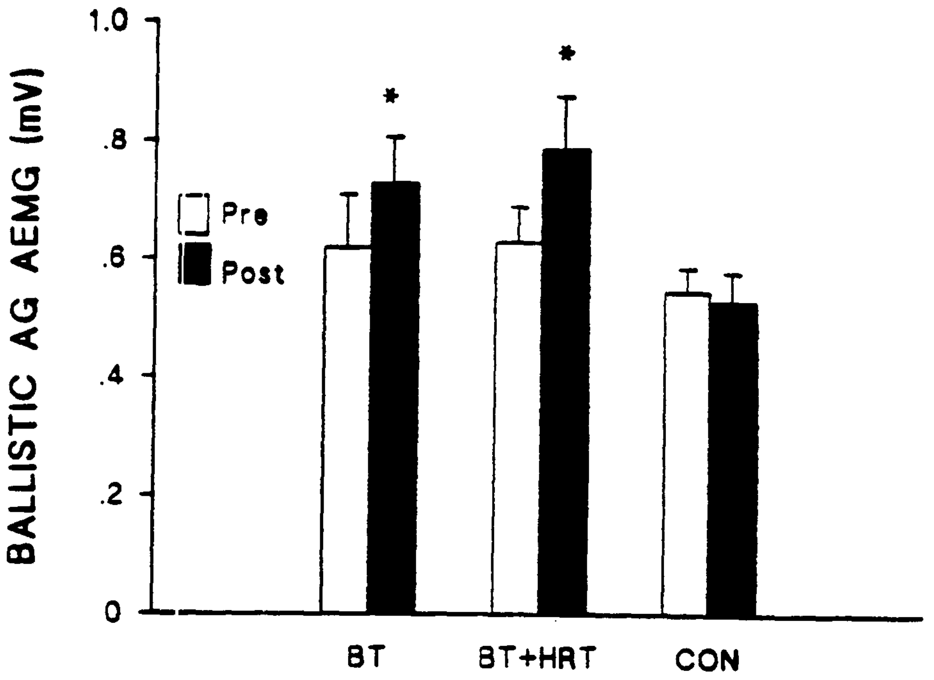
A time main effect was observed for ANT/AG coactivation ratios. The ANT/AG coactivation ratios for the trained group decreased from 0.20 to 0.16 (-20%), whereas the control group showed little change, from 0.17 to 0.19 (12%) (Figure 13).

MVC AEMG. MVC AEMG measures are shown in Table 5. AG AEMG values for both trained and control groups, were similar pre-

Table 5. The agonist (AG) and antagonist (ANT) AEMG and ANT/AG ratios during ballistic 1 RM and MVC testing for the ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms. The (*) symbol indicates a main effect for time. The (†) symbol indicates a relative (percent) difference compared to the CON arm (P≤0.05). Values are means ± SE

	BALLISTIC ACTION			1 RM			MVC		
	AG (mV)	ANT (mV)	ANT/AG	AG (mV)	ANT (mV)	ANT/AG	AG (mV)	ANT (mV)	ANT/AG
BT ARM									
PRE	0.62 ±0.09	0.08 ±0.01	0.15 ±0.02	0.72 ±0.10	0.12 ±0.02	0.20 ±0.04	0.80 ±0.10	0.16 ±0.03	0.20 ±0.02
POST	0.73* ±0.08	0.10* ±0.01	0.15 ±0.02	0.81 ±0.11	0.11 0.01	0.16* ±0.04	0.87 ±0.09	0.17 ±0.03	0.20 ±0.03
% Diff.	**17.7**	**25.0**	**0.0**	**12.5**	**-8.3**	**-20.0**	**8.8**	**6.3**	**0.0**
BT+HRT ARM									
PRE	0.63 ±0.06	0.09 ±0.01	0.15 ±0.01	0.71 ±0.12	0.14 ±0.02	0.20 ±0.03	0.80 ±0.15	0.20 ±0.03	0.25 ±0.02
POST	0.79* ±0.09	0.11* ±0.01	0.15 ±0.02	1.01† ±0.18	0.15 ±0.03	0.16* ±0.04	0.84 ±0.09	0.18 ±0.02	0.21 ±0.02
% Diff.	**25.4**	**22.4**	**0.0**	**42.3**	**7.1**	**-20.0**	**5.0**	**-10.0**	**-16.0**
CON ARM									
PRE	0.55 ±0.04	0.08 ±.02	0.15 ±.01	0.74 ±0.06	0.12 ±0.01	0.17 ±0.03	0.71 ±0.15	0.11 ±.01	0.16 ±0.03
POST	0.53 ±0.03	0.07 ±0.01	0.13 ±0.01	0.65 ±0.07	0.11 ±0.1	0.19 ±0.03	0.73 ±0.16	0.11 ±.02	0.15 ±0.03
% Diff.	**-3.6**	**-12.5**	**-13.3**	**-12.2**	**-8.3**	**11.8**	**2.8**	**0.0**	**-6.3**

Figure 11. Ballistic triceps (AG) average integrated EMG (AEMG) (top), and biceps (ANT) average integrated EMG (AEMG) (bottom) in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(☐) and post-testing(■). * significant increase pre- to post-training ($P \leq 0.05$). Values are means ± SE.


BALLISTIC AG AEMG (mV)
1.0
.8
.6
.4
.2
0
Pre
Post
*
*
BT
BT+HRT
CON

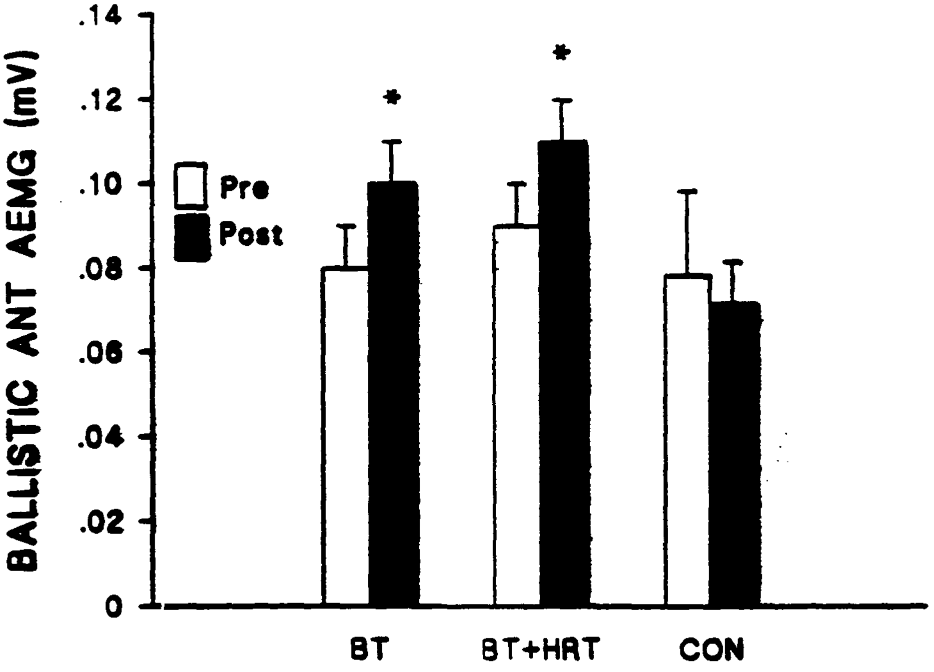
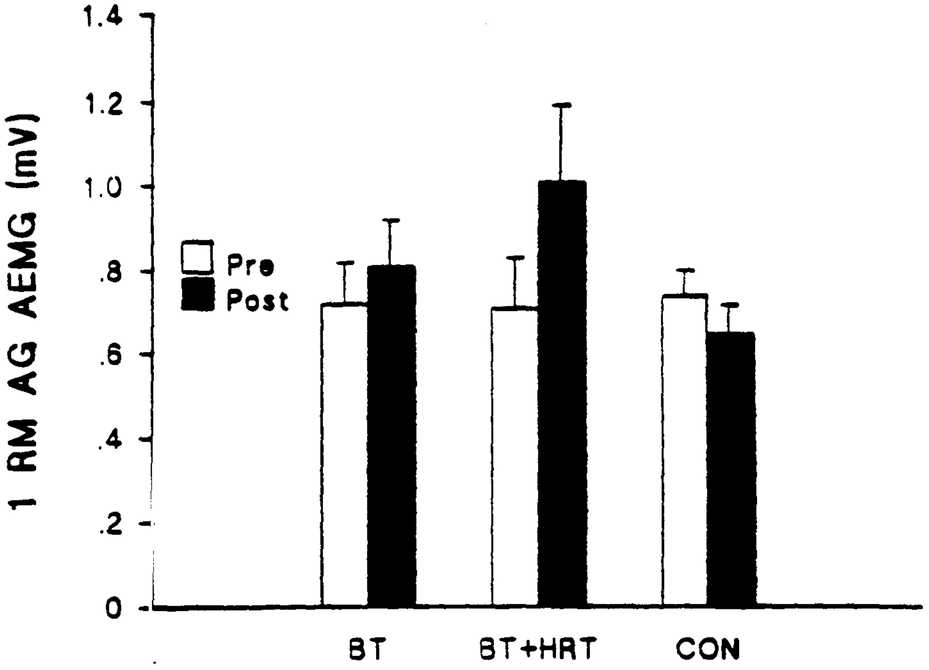

BALLISTIC ANT AEMG (mV)
.14
.12
.10
.08
.06
.04
.02
0
Pre
Post
*
*
BT
BT+HRT
CON

Figure 12. 1 RM triceps (AG) average integrated EMG (AEMG) (top), and biceps (ANT) average integrated EMG (AEMG) (bottom) in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(☐) and post-testing(■). Values are means ± SE.


1 RM AG AEMG (mV)
1.4
1.2
1.0
.8
.6
.4
.2
0
Pre
Post
BT
BT+HRT
CON

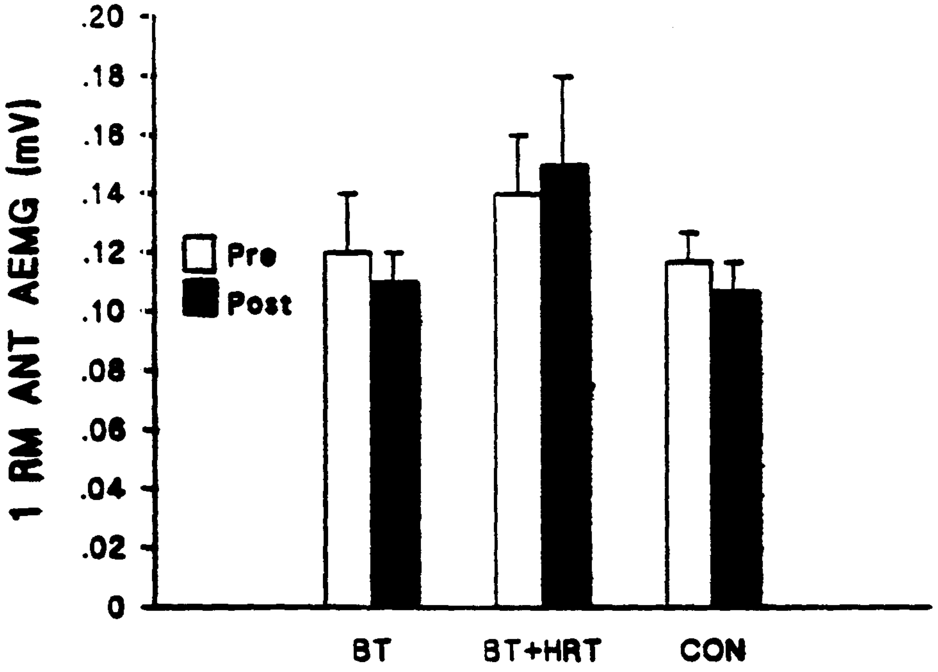
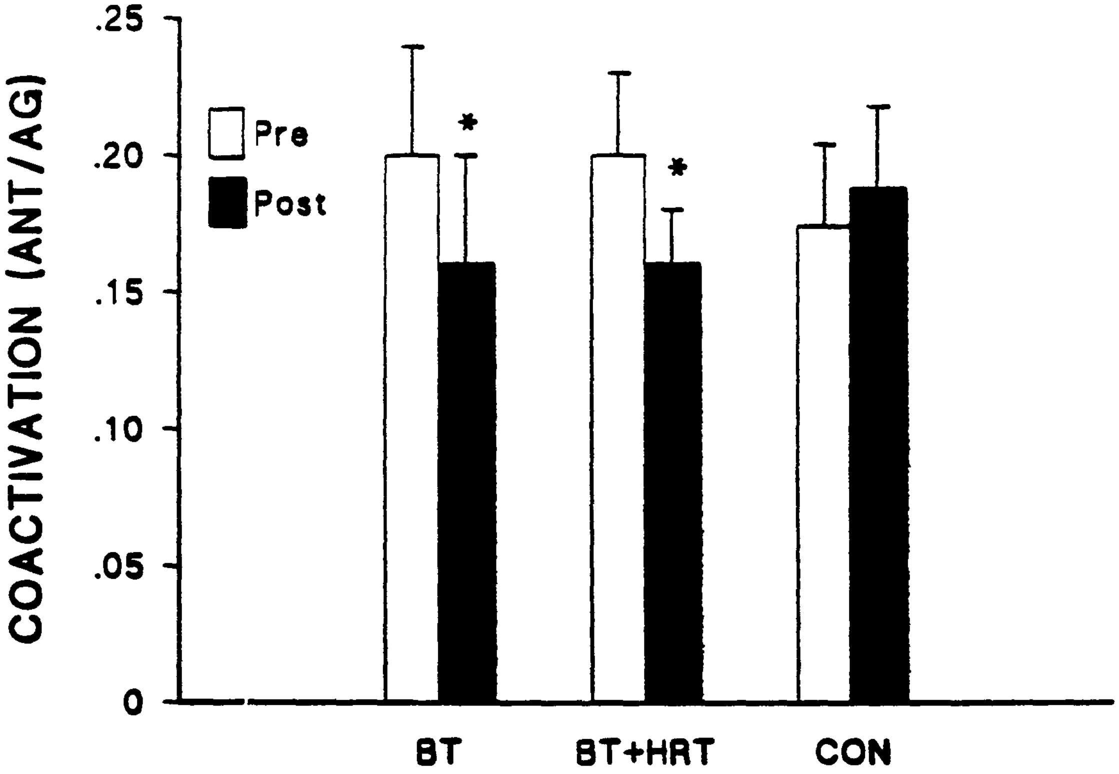

1 RM ANT AEMG (mV)
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
Pre
Post
BT
BT+HRT
CON

Figure 13. 1 RM coactivation ratios (ANT/AG) in ballistic (BT), ballistic and heavy resistance (BT+HRT) and control (CON) arms pre-(□) and post-testing(■). * significant decrease pre- to post-training (P≤0.01). Values are means ± SE.


COACTIVATION (ANT/AG)
.25
.20
.15
.10
.05
0
Pre
Post
*
*
BT
BT+HRT
CON

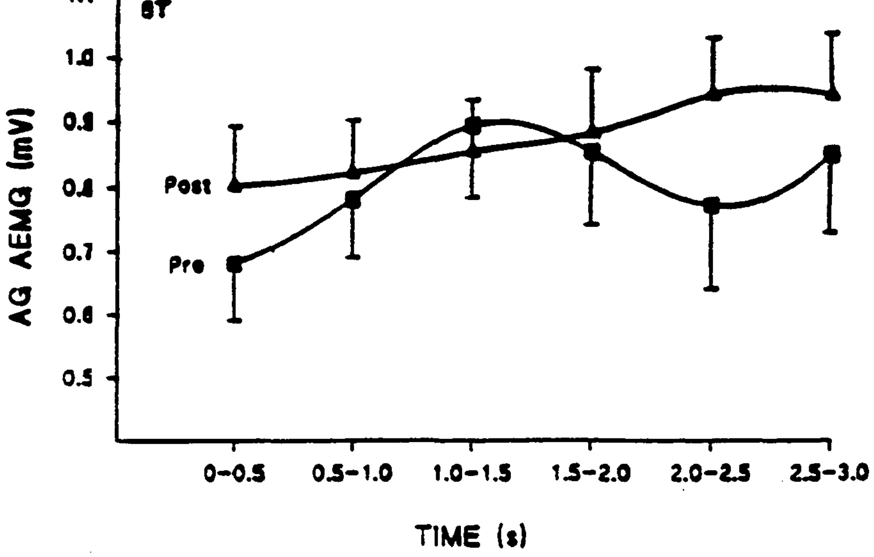
and post-training (collapsed across time intervals). However, a time interval main effect was evident for both groups. AG AEMG measurements increased throughout the six, 0.5 s time intervals (0-3 s). Nonetheless, only the training group displayed a time (pre-post) × time interval interaction. Figure 14 indicates that the AG AEMG for the BT arm significantly increased by 18% (0.68 to 0.80 mV) and 19% (0.78 to 0.93 mV), whereas the BT+HRT arm increased by 4% (0.67 to 0.70 mV) and 33% (0.80 to 1.06 mV) at the time intervals of 0-0.5 and 2.0-2.5 s, respectively.

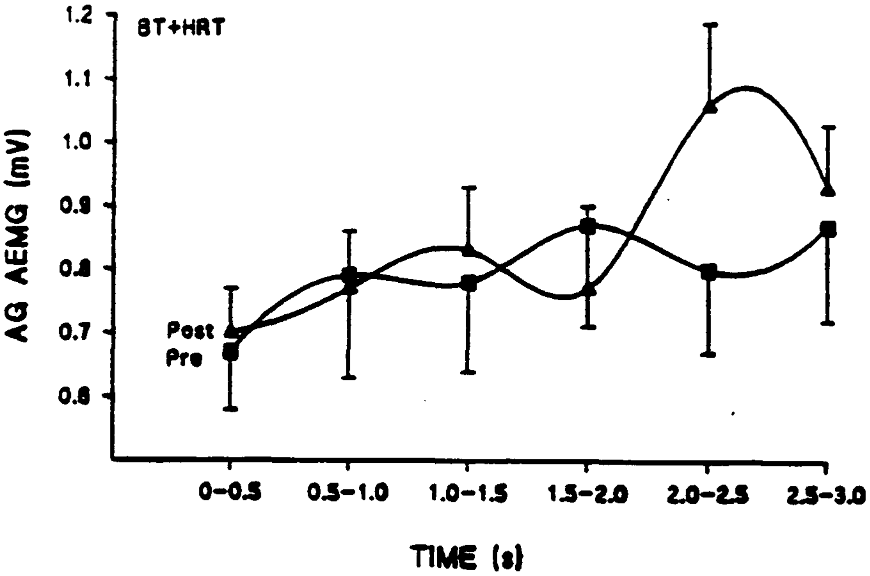
ANT AEMG measures did not show a significant time main effect or time × time interval interaction for either group, comparing pre- with post-testing. However, a time interval main effect was evident for both groups. ANT AEMG values increased throughout the six, 0.5 s time intervals (Figure 15).

The ANT/AG coactivation ratios did not significantly change for either trained or control groups, comparing pre- with post-test values. Nonetheless, a time interval main effect was seen in only the trained group, the 0-0.5 interval was significantly smaller than the 2.5-3.0 interval.

Fibre Areas. As expected, the type I fibres were significantly smaller than either type IIa or IIb fibres. In both the trained and control groups, type I fibre areas were 54 and 60% of type IIa and 57 and 63% of type IIb fibres. An arm × fibre type ×

Figure 14. Isometric MVC triceps (AG) integrated AEMG divided into six 0.5 s intervals , for ballistic (BT, top), ballistic and heavy resistance (BT+HRT, middle) and control arms (CON, bottom) pre-(■) and post-testing (▲). The trained group showed significant increases pre- to post-training at the 0-0.5 and 2.0-2.5 time intervals ($P \leq 0.01$). Values are means ± SE.


BT
AG AEMG (mV)
1.0
0.9
0.8
0.7
0.6
0.5
Post
Pre
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
TIME (s)


BT+HRT
AG AEMG (mV)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
Post
Pre
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
TIME (s)

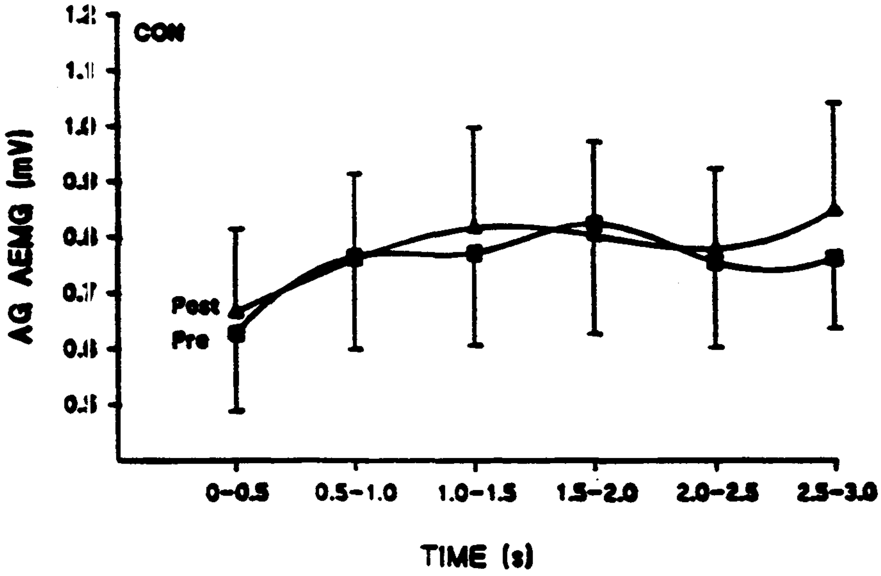
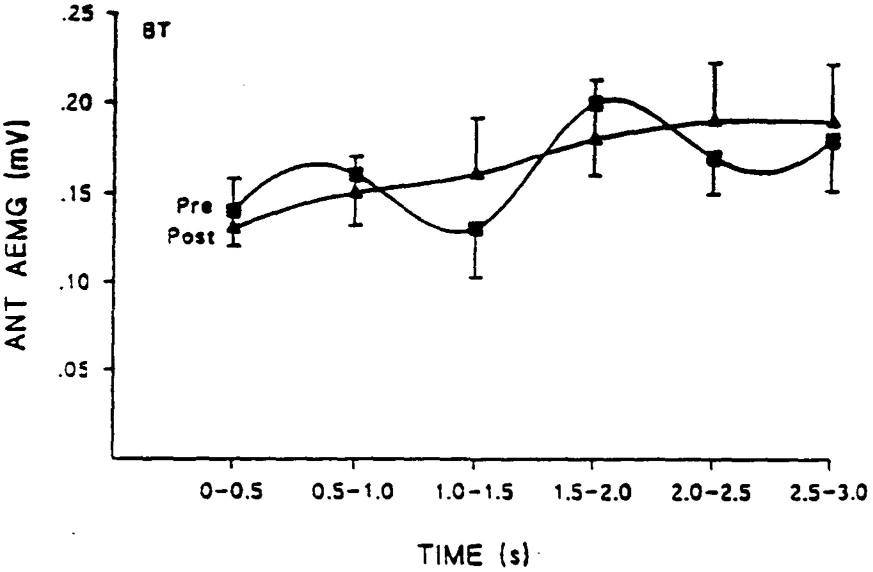
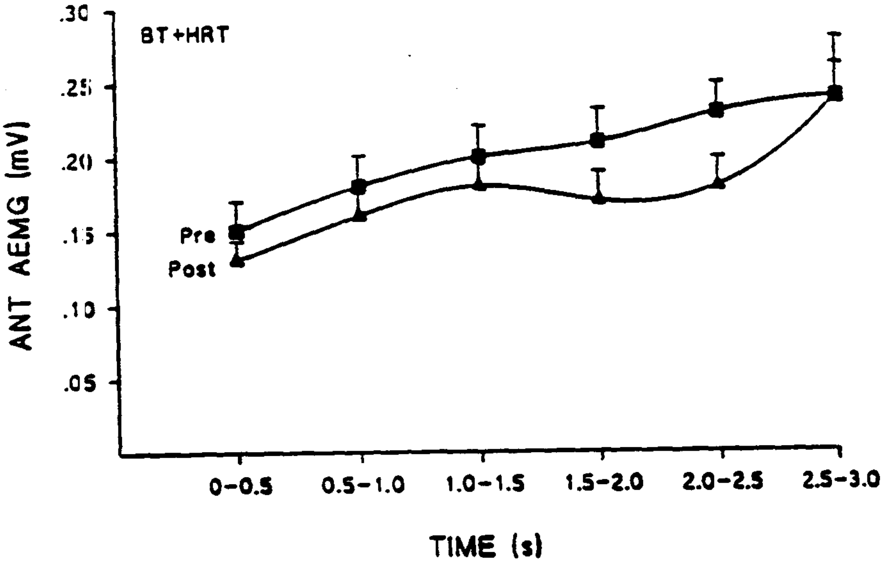
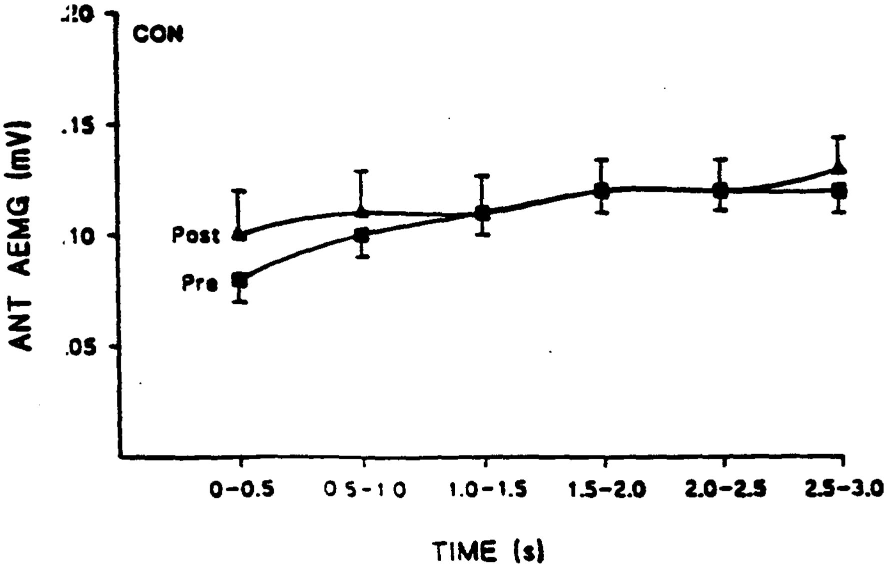

CON
AG AEMG (mV)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
Post
Pre
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
TIME (s)

Figure 15. Isometric MVC triceps (ANT) integrated AEMG divided into six 0.5 s intervals , for ballistic (BT, top), ballistic and heavy resistance (BT+HRT, middle) and control arms (CON, bottom) pre-(■) and post-testing (▲). Values are means ± SE.


BT
ANT AEMG (mV)
.25
.20
.15
.10
.05
Pre
Post
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
TIME (s)


BT+HRT
ANT AEMG (mV)
.30
.25
.20
.15
.10
.05
Pre
Post
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
TIME (s)


CON
ANT AEMG (mV)
.20
.15
.10
.05
Post
Pre
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
TIME (s)

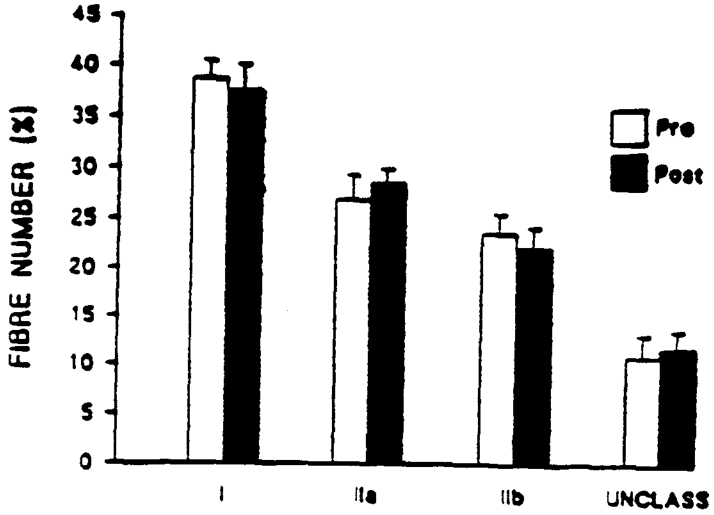
time interaction (ANOVA, arm × fibre type × time) was found for the trained group. This interaction indicated that the BT+HRT arm developed a preferential increase in fibre area for both IIa (6184 to 7086 μm, 27%) and IIb (5714 to 6734 μm, 18%) fibres, with no significant increase in type I fibre area (3503 to 3828 μm, 9.3%) (Figure 16). No significant fibre area change occurred for either the BT arm or the control group.

Fibre Distribution. The BT+HRT arm demonstrated a significant decrease in the percent population of type IIb fibres (22% to 18.8%), comparing pre- with post-test values (ANOVA, arm × % fibre type number × time). The BT arm and control group showed no significant changes (Figure 17-18).

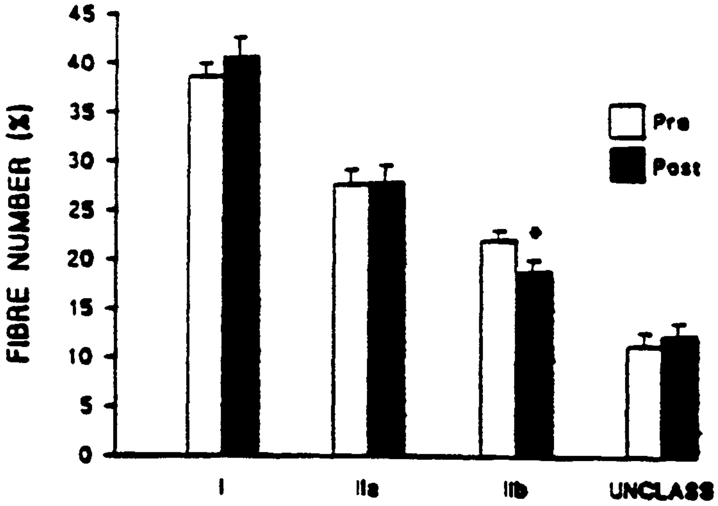
Figure 16. Fibre areas in ballistic (BT), ballistic and heavy resistance (BT+HRT), and control arms pre-(□) and post-testing(■). * significant increase pre- to post-training (P≤0.01). Values are means ± SE.


Fibre Area (µm²)
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
0
I
IIa
IIb
*
*
PRE
POST
BT+HRT
PRE
POST
BT
PRE
POST
CON

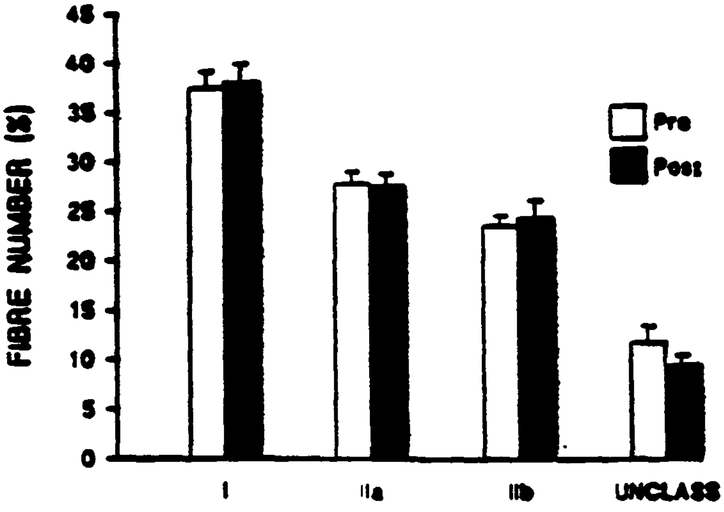
Figure 17. Percent fibre distribution (type I, IIa, IIb, and unclassified) for the ballistic and heavy resistance trained (BT+HRT, top), the ballistic trained (BT, middle) and control arms (CON, bottom) pre-(☐) and post-testing(■). * significant decrease pre- to post-training ($P \leq 0.01$). Values are means ± SE.


FIBRE NUMBER (%)
0
5
10
15
20
25
30
35
40
45
Pre
Post
I
IIa
IIb
UNCLASS

BT

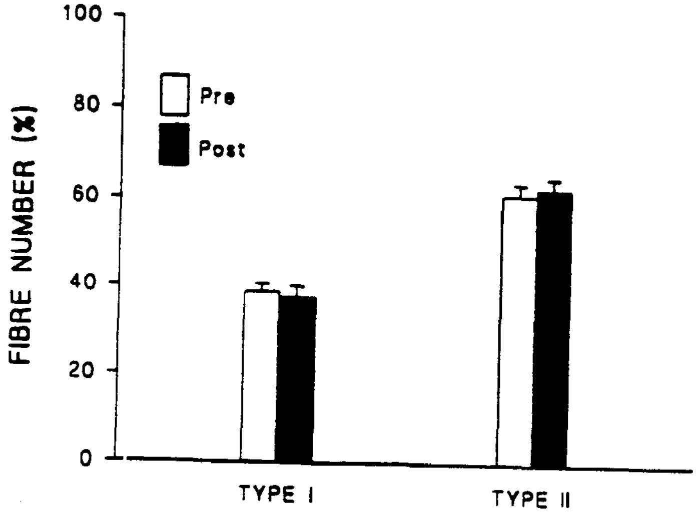

FIBRE NUMBER (%)
0
5
10
15
20
25
30
35
40
45
Pre
Post
*
I
IIa
IIb
UNCLASS

BT+HRT

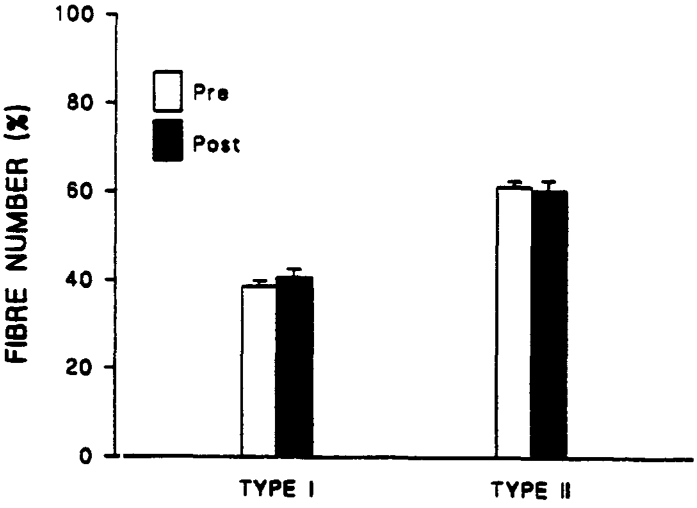

FIBRE NUMBER (%)
0
5
10
15
20
25
30
35
40
45
Pre
Post
I
IIa
IIb
UNCLASS

CON

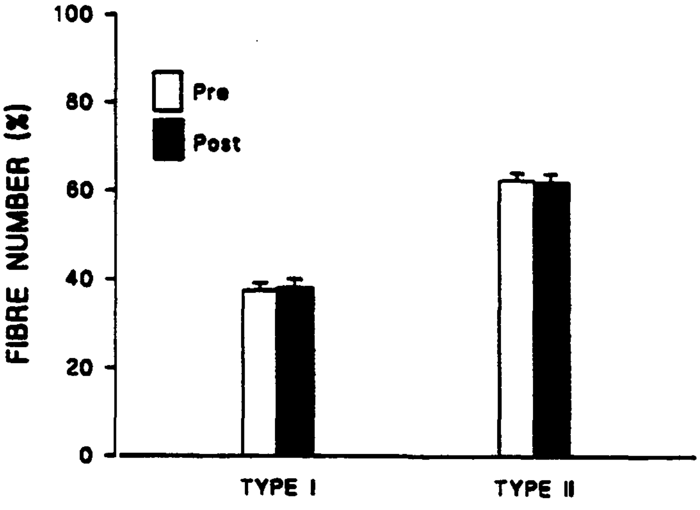
Figure 18. Precent fibre distribution of type I and type II fibres for the ballistic and heavy resistance trained (BT+HRT, top), the ballistic trained (BT, middle), and control arms (CON, bottom) pre-(□) and post-testing(■).


100
80
60
40
20
0
FIBRE NUMBER (%)
Pre
Post
TYPE I
TYPE II

BT


100
80
60
40
20
0
FIBRE NUMBER (%)
Pre
Post
TYPE I
TYPE II

BT+HRT


100
80
60
40
20
0
FIBRE NUMBER (%)
Pre
Post
TYPE I
TYPE II

CON

4.0 DISCUSSION

The major finding of the present study was that supplementary heavy resistance training caused muscle hypertrophy, particularly of the type II fibres, but did not promote significant improvement in ballistic performance with loads equal to or less than 10% of maximal isometric force. It thus appears that with loads ≤ 10% of the isometric maximum, it is not the number of active cross-bridges which limits performance, but rather their maximum cycling rate. This view is supported by studies showing that maximum shortening velocity of unloaded muscle (V_{max}) is independent of the number of active cross-bridges, but dependant on maximum cross-bridge cycling rate of the "fastest" fibres within the muscle (Edman et al., 1978).

Although there were no significant differences between the ballistic and ballistic plus supplementary heavy resistance training arms after training for all ballistic measures tested, small differences in peak velocity gains between the training arms (BT = 2.3%; BT+HRT = 6.1%) could result in much larger differences in performance, for example, throwing distance. A 3.8% peak velocity difference (6.1% - 2.3% = 3.8%) between training arms in velocity improvement would result in a ~ 8% difference in throwing distance (calculation based on projectile equation using a 45° trajectory).

If the training had increased the proportion of type II fibres within triceps, an improvement in ballistic performance might have occurred (if the criterion target load was > 10%), because in human muscles type IIb and IIa fibres may have up to 10 and 3 times, respectively, the V_{max} of type I fibres (Larsson & Moss, 1993). However, in the present study ballistic training had no effect on the percentage of type II fibres and correlations between increases in peak velocity and % type II fibre area were not significant. Furthermore, the supplementary heavy resistance training caused a small but significant decrease in the percentage of IIb fibres (as others have shown; e.g., Staron et al., 1989; Wang et al., 1993).

The present study did not find any alterations in fibre type in the BT arm, which is in agreement (Allemeier et al., 1994; Thorstensson et al., 1975) and disagreement with some previous studies (Andersen et al., 1992; Jansson et al., 1990). Studies on sprint training have demonstrated effects on myosin heavy chain (MHC) isoform composition in skeletal muscle. After training, sprinters showed a decrease in muscle fibres displaying only slow MHCs, and a co-existence of IIa and IIb MHC isoforms. A large increase in IIa MHC isoforms was also seen; this suggests that sprint training increases the expression of IIa MHC isoforms as a result of a bi-directional conversion from

IIb and I MHC isoforms (IIb → IIa ← I) (Andersen et al., 1992). In the present study, a relatively high initial percentage of type II fibres in the triceps, compared to the typically studied vastus lateralis muscle, may have made it more difficult for fibre transformation to occur. In addition, other high velocity training studies have failed to show fibre type conversion (Allemeier et al., 1994; Thorstensson et al., 1975). These investigators suggested that this may be due to individual contraction duration, or variations in fibre composition from biopsy to biopsy.

Changes in the evoked contractile properties of muscle would indicate adaptations within the muscle uninfluenced by neural control. In accordance with the effects of BT or BT+HRT training on muscle fibre type distribution, triceps evoked twitch time to peak torque and half relaxation time were not altered in triceps by training. The BT+HRT training did, however, increase twitch peak torque, a probable reflection of the hypertrophy induced by this training. In contrast, other studies have not found increases in evoked twitch peak torque despite increases in voluntary strength after training (Davies & Young, 1983; Davies et al., 1985).

The present study found specific adaptations in evoked contractile properties, which differed depending on the training arm (BT or BT+HRT). The BT arm did not show significant changes in either peak torque, maximum rate of torque development or maximum rate of torque relaxation, whereas the BT+HRT arm displayed significant changes in these measures. One other study, conducted by Duchateau and Hainaut (1984), showed training specific adaptations in evoked twitch contractile properties. Duchateau and Hainaut (1984) found training mode specific adaptations in subjects that had trained their adductor pollicis with either isometric or dynamic resistance for 3 months. Dynamic training produced a greater maximum rate of torque development and maximum rate of torque relaxation compared to isometric training.

Agonist AEMG in ballistic actions increased after training. This finding both confirms (Hakkinen et al., 1985) and contradicts other studies (Behm & Sale, 1993; Hakkinen & Komi, 1986). Differences in muscle activation found in the previously cited studies may in part be explained by differences in movement type and/or the muscle group tested. The present finding suggests that some form of neural adaptation occurred; however, like the ballistic performance itself, BT and BT+HRT produced similar AEMG increases. The individual AEMG components, whether they be motor unit recruitment or rate coding, could not be distinguished. Since isometric ballistic actions last for approximately 80- 150 ms (Sale, 1987), which is similar to the present dynamic study (~ 200 ms), and MUs may fire at initial frequencies of up to 120 Hz during brief maximal ballistic actions, (Desmedt & Godaux, 1977) firing frequency adaptation may be a more critical adaptation during ballistic training.

The supplementary HRT was not beneficial, but neither was it detrimental to improving ballistic performance. This finding is in agreement with some (Schultz, 1966; Sleivert et al., 1995) and is in disagreement with other previous studies (Tesch & Larsson, 1982). Tesch and Larsson (1982) showed in a cross-sectional study that bodybuilders and weight lifters possessed impaired torque generating ability at high velocities. However, impaired high velocity strength, accompanied by hypertrophy, may be caused by specific neural adaptations resulting from slow velocity strength training.

The results suggest that the HRT was an effective substitute for the BT that otherwise would have been performed (i.e, extra ballistic training by BT arm), or that the amount of ballistic training done by the BT arm was in excess of that needed for an optimal training response.

The primary function of traditional weight training is to enhance muscular strength. Studies which have examined the effectiveness of HRT in improving speed performance with loads of ≤10% MVC have been inconclusive (Sleivert et al., 1995; Whitley & Smith, 1966). Whitley and Smith (1966) designed an experiment to compare the effects of isometric-isotonic training (A), dynamic-overload training (B), and free swing training (C) on the speed and strength of relatively unloaded lateral swinging arm movement (≤ 10% MVC). They found that program A and B significantly increased lateral swing arm speed, whereas program C failed to increase lateral swing arm speed. Sleivert et al. (1995) had subjects divided into a sprint-sprint, single-joint strength trained plus sprint, and a multi-joint strength trained plus sprint groups. Both single- and multi-joint strength trained plus sprint groups increased 10 repetition maximum strength. However, all groups similarly increased cycle ergometer power output.

Other studies that have examined the effect of HRT on ballistic performance with loads of ≥ 10% MVC, have found that HRT has a positive effect of performance (Berger, 1963; Wilson et al., 1993). Wilson et al. (1993) evaluated training methods for improving sprinting and jumping performance. This study investigated the relative effectiveness of heavy resistance training (squat, 6-10 RM, ~ 85% MVC), drop jump training and weighted jump squat training (with loads equal to 30% of MVC). They concluded that weighted jump squat training caused a significant improvement in 30 m sprinting. All three training protocols improved vertical jump performance, but weighted jump squat training produced the best results. Berger (1963) measured vertical jump height after 4 different training regimens. Group one trained using a 10 RM squat, group two trained with 50 to 60 percent of 10 RM for ten repetitions of jumping squats, group three trained isometrically, and group four trained by vertical jumping. Squat jumping followed by the 10 RM training group improved vertical jumping to the greatest extent, whereas isometric and vertical jumping training did not increase vertical jump performance. Additional research will be needed to determine the minimum load at which supplementary HRT is beneficial to high velocity performance.

The effect of HRT, including isometric training, on ballistic performance, may depend on whether the training actions are executed with the intent to move as rapidly as possible. Behm and Sale (1993) found that isometric and high velocity concentric actions produced a similar high velocity specific training response, presumably because both types of actions were performed with the intent to move as quickly as possible. Thus, the central command for both training actions, and the associated motor unit discharge pattern, would have been similar. In the present study, however, HRT was not conducted in this manner. Training actions were characterized by deliberately slow rates of force development. Therefore, the motor control and motor unit discharge patterns were different than that of the ballistic training actions. In the present study the aim of the HRT was to induce type II fibre hypertrophy, and to evaluated its effect on ballistic performance.

Specificity in training has been well demonstrated in terms of movement pattern, contraction type, and contraction velocity

(Morrissey et al., 1995; Sale & MacDougall, 1981). Thus, measured improvements are greatest in tests most similar to the training actions. In the present study, there was some evidence of this specificity (Table 6). The 1 RM increased only in the arm which did supplementary HRT training. The BT+HRT training might also have been expected to cause greater increases in isometric strength (MVC), but this did not occur, despite the fact that the HRT training caused hypertrophy. This finding is not unique, however, since previous studies have shown that weight training failed to increase isometric strength despite inducing hypertrophy (Sale et al., 1992; Sleivert et al., 1995).

The EMG results corresponded to the performance results in that triceps AEMG in the 1 RM test tended to increased more after HRT than only BT, but in the ballistic and isometric MVC action tests, the AEMG results were similar. Narici and colleagues (1989) have attributed the increased EMG after resistance training to neural factors residing in the inhibitory or facilitory synaptic pathways, which act to disinhibit higher cortical centres or to inhibit the Renshaw cell and Golgi tendon organ reflex. Westing et al. (1988) have suggested that there is an inhibitory feedback loop in low velocity, high force contractions. This mechanism, if active, can reduce force production. Low velocity training possibly raises the low velocity portion of the curve through a disinhibition response to training, but is not transferable to isometric actions.

Table 6. Percent increase in strength, agonist AEMG and twitch PT measurements. The (*) symbol indicates a main effect for time ($P \le 0.05$).

Strength Increases

	BT	BT+HRT
Ballistic PT	19.9*	20.4*
MVC PT	16.0*	13.0*
1 RM	2.6	23.6*

AEMG Agonist

	BT	BT+HRT
Ballistic	17.7*	25.4*
MVC	8.8	5.0
1 RM	12.5	42.3

Twitch PT

	BT	BT+HRT
Evoked PT	1.6	10.4*

In addition, the present study found that isometric MVC AG AEMG increased at the time intervals of 0-0.5 s and 2.0-2.5 s pre- to post-testing (collapsed across training arm). Although a significant interaction was not found between training arm and time interval, a trend suggested that the AG AEMG for the BT arm showed a greater increase at the 0.0-0.5 s interval, whereas the AG AEMG for the BT+HRT arm displayed a greater increase at the 2.0-2.5 s interval. Only one previous study demonstrated similar AEMG training specificity. Hakkinen et al. (1985) found that jump training caused a significant increase in EMG at the onset of the movement, whereas conventional heavy resistance training produced a small increase in EMG later in the activation period.

In the present investigation, ballistic action maximum rate of torque development, time to peak torque, peak velocity and peak power significantly increased for both the trained and control group, although the percentage increases in the trained group were clearly larger in the maximum rate of torque development and peak power measures (Table 3). The significant increase observed in the control group is surprising, because during testing all subjects received the same instructions to perform movements as forcefully and quickly as possible. Furthermore, all subjects were familiarized with all test movements prior to pre-testing. One possible explanation for the significant increases found in the control group, may be related to the nylon rope which connected the weight stack to the ballistic apparatus. The initial rope was replaced during post-testing because it broke during the training phase of the experiment. Therefore, different ropes which may have had different compliances were used for pre- and post-testing. The nylon ropes used had low compliance; nevertheless, a small difference in the compliance of the two ropes may have had a systematic effect on the ballistic performance measures. Alternatively, the familiarization and pre-test sessions induced a learning effect that was transferred to the post-test session.

In summary, the present study found that supplementary heavy resistance training increased type II fibre size, but did not promote improvement in high velocity ballistic actions with a load ≤ 10 % MVC. Supplementary heavy resistance training decreased the percentage of type IIB fibres, whereas the proportion of type IIa fibres remained unchanged. This fibre transformation was not detrimental to improving ballistic performance.

Neural adaptations were found after ballistic training; triceps AEMG increased along with the corresponding ballistic performance measures; however, these adaptations were similar in both training arms.

Specificity in training was also demonstrated in the study. The 1 RM showed a greater increase in the supplementary heavy resistance arm with a corresponding greater increase in triceps

AEMG. Furthermore, during the MVC measurement, ballistic training produced a greater increase in triceps AEMG at the onset of movement, whereas the supplementary heavy resistance training arm showed a greater increase in triceps AEMG later in the activation period.

Prior research which has examined the effect of heavy resistance training on speed performance with various criterion loads has been inconclusive. Future research in this area should be directed at isolating the minimum criterion performance load, expressed as a percentage of the isometric maximum (% MVC), that would benefit from supplementary heavy resistance training.

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Appendix 1

Tables of Raw Data

CONTRACTILE PROPERTIES **BALLISTIC ARM**

PRE TEST

Subjects	PT N.m	TPT ms	MRTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP1/2R N.m.s	1/2R ms
Paul, M	17.92	62.60	515.82	-158.46	2.44	1.83	80.49
Jeremy, M	6.26	59.95	170.36	-76.70	0.07	0.05	59.29
Geoff, V	9.64	55.32	285.12	-69.87	1.64	1.11	103.01
Kevin, H	10.64	63.93	236.36	-72.25	1.62	1.14	97.71
Colin, M	21.74	57.63	506.08	-182.99	3.08	2.23	99.37
Rob, A	14.61	54.99	421.88	-107.03	2.06	1.42	85.46
Todd, A	14.04	64.59	331.87	-108.52	2.19	1.45	90.10
Mark, H	11.66	61.94	306.82	-97.22	1.59	1.16	82.48
Morgan, L	8.23	56.64	216.74	-93.65	1.04	0.67	66.91
Mean	12.75	59.73	332.34	-107.41	1.75	1.23	84.98
SE	1.73	1.31	43.94	13.81	0.30	0.22	5.20

POST TEST

Subjects	PT N.m	TPT ms	MRTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP1/2R N.m.s	1/2R ms
Paul, M	16.31	59.62	436.74	-138.54	2.20	1.53	81.15
Jeremy, M	6.23	54.99	154.00	-66.60	0.71	0.51	72.87
Geoff, V	14.46	59.95	435.55	-106.96	2.48	1.50	92.08
Kevin, H	13.35	66.25	291.06	-151.33	1.91	1.35	86.45
Colin, M	17.89	64.26	455.47	-154.60	2.67	1.88	91.42
Rob, A	12.45	57.97	411.47	-99.60	1.75	1.20	80.16
Todd, A	16.04	69.23	397.20	-122.79	2.48	1.68	88.44
Mark, H	9.53	62.93	314.25	-82.65	1.37	0.95	82.81
Morgan, L	11.12	60.28	269.06	-178.98	1.29	0.82	57.97
Mean	13.04	61.72	351.64	-122.45	1.87	1.27	81.48
SE	1.30	1.55	35.72	12.98	0.23	0.16	3.78

CONTRACTILE PROPERTIES **BALLISTIC +RESISTANCE ARM**

PRE TEST

Subjects	PT N.m	TPT ms	MRTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP1/2R N.m.s	1/2R ms
Paul, M	11.19	61.28	302.66	-93.73	1.69	1.08	76.85
Jeremy, M	8.43	67.24	216.74	-85.03	1.02	0.74	65.58
Geoff, V	9.75	58.96	294.93	-60.95	1.92	1.27	118.25
Kevin, H	14.98	65.58	360.04	-106.14	2.25	1.67	91.75
Colin, M	14.18	62.27	321.39	-139.44	1.87	1.37	85.79
Rob, A	13.77	63.93	354.39	-100.19	1.97	1.40	86.12
Todd, A	15.58	61.61	362.12	-106.44	2.60	1.73	100.70
Mark, H	11.83	61.94	277.09	-85.33	1.82	1.18	90.43
Morgan, L	12.33	61.28	309.49	-100.49	1.84	1.28	93.74
Mean	12.45	62.68	310.98	-97.53	1.89	1.30	89.91
SE	0.85	0.89	16.48	7.48	0.15	0.11	5.20

POST TEST

Subjects	PT N.m	TPT ms	MRTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP1/2R N.m.s	1/2R ms
Paul, M	12.94	68.90	382.93	-96.10	2.05	1.33	82.48
Jeremy, M	9.27	61.94	300.58	-102.57	1.13	0.79	71.88
Geoff, V	13.34	53.33	395.71	-125.76	2.43	1.57	108.65
Kevin, H	15.28	67.57	337.44	-106.73	2.47	1.74	97.38
Colin, M	17.21	63.27	388.87	-159.95	2.34	1.66	85.46
Rob, A	16.15	53.99	504.82	-199.52	2.25	1.63	89.43
Todd, A	14.61	66.25	325.55	-126.06	2.17	1.45	84.80
Mark, H	11.08	65.58	297.90	-91.87	1.74	1.25	97.38
Morgan, L	14.15	65.58	319.01	-130.22	1.99	1.33	78.17
Mean	13.78	62.93	361.42	-126.53	2.06	1.42	88.40
SE	0.87	2.00	23.17	12.22	0.15	0.10	3.97

CONTRACTILE PROPERTIES **CONTROL ARM**

PRE TEST

Subjects	PT N.m	TPT ms	MRTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP1/2R N.m.s	1/2R ms
Jay, M	13.81	57.97	361.82	-147.46	1.65	1.15	70.55
Ian,T	15.92	67.24	439.42	-136.46	2.17	1.6	76.85
Darcy,P	8.57	58.98	238.14	-111.19	1.09	0.72	63.93
Neal,K	11.16	60.62	287.49	-108.22	1.44	0.99	72.54
Rob,H	12.07	64.26	324.66	-156.08	1.55	1.04	68.23
Greg,K	10.28	62.27	254.49	-123.98	1.06	0.77	53.33
Lee,B	12.6	64.28	333.58	-138.47	2.05	1.18	74.53
Paul,H	10.51	63.27	293.14	-111.79	1.51	1.02	83.8
Craig,H	12.45	47.7	440.9	-114.46	1.53	1.13	83.8
Brad,M	13.31	58.63	366.58	-93.06	1.88	1.41	94.73
Mean	12.07	60.52	334.02	-124.12	1.59	1.10	74.23
SE	0.69	1.79	23.26	6.62	0.12	0.09	3.86

POST TEST

Subjects	PT N.m	TPT ms	MRTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP1/2R N.m.s	1/2R ms
Jay, M	15.42	61.28	434.96	-164.71	1.84	1.32	69.23
Ian,T	13.74	64.59	437.93	-125.17	1.82	1.28	70.22
Darcy,P	9.23	58.3	230.71	-111.49	1.1	0.74	63.6
Neal,K	10.48	57.97	321.98	-140.63	1.19	0.8	58.96
Rob,H	13.5	65.58	402.25	-200.98	1.76	1.2	73.2
Greg,K	10.7	57.97	316.63	-168.57	1.12	0.77	49.69
Lee,B	13.77	66.91	417.12	-117.14	1.92	1.37	80.82
Paul,H	11.21	60.95	340.12	-141.81	1.52	0.98	72.87
Craig,H	11.61	64.59	378.47	-123.08	1.44	1.04	69.23
Brad,M	13.08	59.29	330.31	-96.62	1.78	1.3	85.79
Mean	12.27	61.74	361.05	-139.02	1.55	1.08	69.36
SE	0.64	1.14	21.77	10.46	0.11	0.08	3.44

BALLISTIC PERFORMANCE **BALLISTIC ARM**

PRE TEST

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	RTD (N.m.s-1)	Peak Power (watts)	AG Duration (ms)	AG AEMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT/AG AEMG
Rob,A	0.18	14.06	128.18	19.99	0.07	505.81	156.22	0.23	0.69	0.23	0.13	0.18
Colin,M	0.19	14.59	136.43	24.35	0.09	545.09	215.71	0.24	0.82	0.24	0.06	0.08
Morgan,L	0.20	12.34	109.11	19.65	0.08	439.89	132.21	1.00	0.37	1.00	0.08	0.19
Kevin,H	0.18	14.16	145.01	20.27	0.08	502.90	153.85	0.92	1.15	0.92	0.06	0.06
Mark,H	0.21	12.61	108.88	20.25	0.08	477.57	161.54	1.00	0.48	1.00	0.06	0.13
Todd,A	0.21	11.98	110.45	20.78	0.08	514.54	143.62	0.24	0.39	0.24	0.08	0.21
Jeremy,M	0.22	11.44	101.90	14.93	0.10	360.88	102.13	0.26	0.41	0.26	0.12	0.30
Paul,M	0.21	12.36	112.86	20.30	0.10	375.86	162.50	0.26	0.73	0.26	0.07	0.10
Geoff,V	0.19	14.94	146.54	15.72	0.09	315.19	157.79	0.24	0.55	0.24	0.08	0.15
Mean	0.20	13.17	122.15	19.58	0.09	448.64	153.95	0.49	0.62	0.49	0.08	0.15
SE	0.00	0.43	5.71	0.93	0.00	26.85	10.05	0.12	0.09	0.12	0.01	0.03

POST TEST

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	RTD (N.m.s-1)	Peak Power (watts)	AG Duration (ms)	AG AEMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT/AG AEMG
Rob,A	0.20	13.06	127.09	23.15	0.07	781.80	160.11	0.24	0.61	0.24	0.11	0.18
Colin,M	0.20	13.66	128.99	25.93	0.08	733.97	217.48	0.24	0.80	0.24	0.09	0.12
Morgan,L	0.20	14.03	142.46	25.76	0.08	651.43	214.07	0.24	0.78	0.24	0.13	0.17
Kevin,H	0.13	14.20	140.59	23.25	0.07	753.36	189.69	0.24	1.09	0.24	0.10	0.10
Mark,H	0.21	13.45	125.82	25.06	0.09	654.20	203.43	0.24	0.78	0.24	0.11	0.14
Todd,A	0.19	13.73	146.99	26.14	0.07	860.80	212.04	0.24	0.45	0.24	0.10	0.24
Jeremy,M	0.22	11.51	113.90	18.56	0.08	558.48	127.26	0.27	0.69	0.27	0.11	0.15
Paul,M	0.22	12.95	117.61	23.69	0.10	562.93	185.28	0.26	0.98	0.26	0.07	0.07
Geoff,V	0.18	15.13	154.40	19.64	0.07	609.99	164.01	0.22	0.43	0.22	0.11	0.25
Mean	0.19	13.53	133.09	23.47	0.08	685.22	185.93	0.24	0.73	0.24	0.10	0.15
SE	0.01	0.33	4.59	0.92	0.00	34.66	10.15	0.00	0.08	0.00	0.01	0.02

BALLISTIC PERFORMANCE **BALLISTIC + RESISTANCE ARM**

PRE TEST

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	RTD (N.m.s-1)	Peak Power (watts)	AG Duration (ms)	AG AEMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT/AG AEMG
Rob,A	0.19	14.18	129.03	20.55	0.07	634.30	148.74	0.24	0.58	0.24	0.11	0.19
Colin,M	0.23	13.67	132.39	21.18	0.12	328.86	180.60	0.31	0.62	0.31	0.07	0.12
Morgan,L	0.20	13.82	123.68	20.07	0.09	470.45	178.84	0.25	0.89	0.25	0.10	0.12
Kevin,H	0.21	13.68	126.86	18.95	0.11	348.65	151.25	0.27	0.68	0.27	0.08	0.12
Mark,H	0.21	12.92	119.93	20.99	0.09	507.84	172.79	0.24	0.73	0.24	0.14	0.19
Todd,A	0.20	12.67	112.36	25.10	0.08	697.12	173.65	0.96	0.26	0.96	0.05	0.20
Jeremy,M	0.25	10.86	106.36	15.59	0.12	333.81	121.33	0.29	0.49	0.29	0.07	0.15
Paul,M	0.22	11.92	106.72	19.09	0.10	372.37	157.07	0.26	0.77	0.26	0.08	0.11
Geoff,V	0.19	14.28	131.13	15.46	0.09	346.32	136.39	0.23	0.64	0.23	0.10	0.16
Mean	0.21	13.11	120.94	19.67	0.10	448.86	157.85	0.34	0.63	0.34	0.09	0.15
SE	0.01	0.38	3.41	0.99	0.01	46.39	6.84	0.08	0.06	0.08	0.01	0.01

POST TEST

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	RTD (N.m.s-1)	Peak Power (watts)	AG Duration (ms)	AG AEMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT/AG AEMG
Rob,A	0.20	14.26	134.10	22.51	0.08	646.95	184.10	0.25	0.47	0.25	0.10	0.22
Colin,M	0.20	14.06	137.83	23.19	0.10	581.18	220.05	0.24	0.82	0.24	0.12	0.14
Morgan,L	0.19	14.88	164.72	27.59	0.07	913.37	246.00	0.22	1.10	0.22	0.22	0.20
Kevin,H	0.20	13.79	128.02	21.58	0.08	607.37	170.03	0.24	0.89	0.24	0.10	0.12
Mark,H	0.21	12.86	118.84	23.62	0.08	674.43	202.13	0.26	0.93	0.26	0.13	0.15
Todd,A	0.20	14.43	134.67	28.36	0.08	925.47	268.24	0.23	0.42	0.23	0.07	0.16
Jeremy,M	0.23	12.56	118.22	20.65	0.10	498.18	168.48	0.27	0.53	0.27	0.09	0.17
Paul,M	0.21	12.62	124.97	23.70	0.08	662.81	185.06	0.26	1.10	0.26	0.07	0.07
Geoff,V	0.18	15.83	164.21	20.96	0.07	650.28	202.60	0.22	0.84	0.22	0.09	0.10
Mean	0.20	13.92	136.18	23.57	0.08	684.45	205.19	0.24	0.79	0.24	0.11	0.15
SE	0.01	0.37	5.82	0.91	0.00	48.00	11.41	0.01	0.09	0.01	0.02	0.02

BALLISTIC PERFORMANCE

CONTROL ARM

PRE TEST

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	RTD (N.m.s-1)	Peak Power (watts)	AG Duration (ms)	AG AEMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT/AG AEMG
Ian,T	0.27	11.65	106.84	20.17	0.14	321.00	8917.37	0.29	0.41	0.29	0.06	0.15
Neal,K	0.26	11.00	98.60	15.66	0.12	304.42	5973.33	0.29	0.58	0.29	0.09	0.16
Craig,H	0.22	13.69	122.16	17.36	0.11	315.47	8307.70	0.25	0.63	0.25	0.12	0.19
Darcy,P	0.22	12.00	103.76	12.80	0.09	304.85	5214.30	0.26	0.52	0.26	0.09	0.17
Greg,K	0.24	12.82	122.19	17.68	0.12	346.47	8340.03	0.27	0.48	0.27	0.08	0.17
Rob,H	0.25	10.50	96.56	17.55	0.13	348.07	6774.53	0.28	0.49	0.28	0.08	0.16
Lee,B	0.30	11.56	103.58	14.63	0.17	216.82	6194.50	0.32	0.60	0.32	0.03	0.05
Paul,H	0.23	12.55	116.16	19.04	0.11	439.45	8170.07	0.26	0.82	0.26	0.07	0.08
Jay,M	0.24	12.58	121.72	19.37	0.13	376.59	9206.77	0.26	0.50	0.26	0.07	0.15
Brad,M	0.23	12.59	121.20	16.33	0.12	330.03	7561.07	0.26	0.46	0.26	0.10	0.21
Mean	0.25	12.09	111.28	17.06	0.13	330.32	130.30	0.27	0.55	0.27	0.08	0.15
SE	0.01	0.31	3.48	0.76	0.01	18.97	7.88	0.01	0.04	0.01	0.01	0.02

POST TEST

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	RTD (N.m.s-1)	Peak Power (watts)	AG Duration (ms)	AG AEMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT/AG AEMG
Ian,T	0.24	11.58	112.23	20.83	0.10	509.88	154.49	0.28	0.30	0.28	0.06	0.21
Neal,K	0.25	11.30	93.00	15.35	0.11	295.97	111.27	0.28	0.45	0.28	0.07	0.15
Craig,H	0.22	14.12	123.43	17.71	0.10	411.13	158.18	0.24	0.72	0.24	0.12	0.17
Darcy,P	0.23	12.66	122.93	13.92	0.10	317.37	104.59	0.28	0.43	0.28	0.06	0.14
Greg,K	0.24	12.90	125.26	18.38	0.11	446.58	150.16	0.26	0.56	0.26	0.07	0.13
Rob,H	0.27	10.72	99.99	18.90	0.14	427.36	129.48	0.30	0.68	0.30	0.09	0.14
Lee,B	0.26	12.06	102.26	13.95	0.14	231.38	110.18	0.30	0.44	0.30	0.03	0.07
Paul,H	0.22	12.87	115.21	18.72	0.09	499.84	155.30	0.26	0.76	0.26	0.06	0.07
Jay,M	0.24	12.66	116.23	19.88	0.12	456.86	166.87	0.26	0.44	0.26	0.07	0.17
Brad,M	0.23	13.42	122.76	18.13	0.11	471.76	156.17	0.27	0.55	0.27	0.09	0.16
Mean	0.24	12.43	113.33	17.58	0.11	406.81	139.67	0.27	0.53	0.27	0.07	0.14
SE	0.01	0.34	3.77	0.80	0.01	31.25	7.81	0.01	0.05	0.01	0.01	0.01

MVC BALLISTIC ARM TORQUE

PRE TEST

Subjects	0.0-0.5 (s) N.m	0.5-1.0 (s) N.m	1.0-1.5 (s) N.m	1.5-2.0 (s) N.m	2.0-2.5 (s) N.m	2.5-3.0 (s) N.m	0.0-3.0 (s) N.m	PT N.m	MRTD N.m.s
Rob,A	31.18	43.60	43.98	43.38	41.78	41.18	40.85	45.04	522.98
Colin,M	22.84	44.70	48.56	44.12	41.54	44.06	40.97	49.28	350.98
Morgan,L	30.92	46.54	48.04	48.58	48.74	45.92	44.79	49.04	778.80
Kevin,H	26.38	39.16	38.40	38.58	37.42	37.86	36.30	39.60	344.43
Mark,H	34.38	50.06	52.76	52.66	51.52	50.36	48.62	53.28	421.70
Todd,A	37.74	50.32	49.18	47.84	46.70	45.90	46.28	50.63	642.59
Jeremy,M	29.88	41.24	42.24	41.68	40.12	39.96	39.19	42.73	427.81
Paul,M	36.78	53.16	53.84	53.76	54.32	54.92	51.13	54.24	484.56
Geoff,V	25.78	33.66	31.16	30.90	27.42	24.02	28.82	34.54	450.95
Mean	30.65	44.72	45.35	44.61	43.28	42.69	41.88	46.49	491.64
SE	1.79	2.17	2.56	2.53	2.88	3.09	2.40	2.32	49.75

POST TEST

Subjects	0.0-0.5 (s) N.m	0.5-1.0 (s) N.m	1.0-1.5 (s) N.m	1.5-2.0 (s) N.m	2.0-2.5 (s) N.m	2.5-3.0 (s) N.m	0.0-3.0 (s) N.m	PT N.m	MRTD N.m.s
Rob,A	34.18	45.82	46.78	46.88	47.30	46.66	44.60	47.31	552.66
Colin,M	48.98	64.06	61.58	59.54	59.68	57.32	58.53	65.03	789.60
Morgan,L	41.34	54.50	56.88	55.20	55.76	55.16	53.14	57.62	749.50
Kevin,H	34.42	43.90	45.24	45.86	46.48	45.54	43.57	47.40	757.80
Mark,H	37.70	51.52	54.36	54.46	52.88	53.02	50.66	54.97	651.76
Todd,A	43.02	56.80	56.88	55.54	53.62	53.34	53.20	57.62	809.30
Jeremy,M	35.44	49.62	49.12	48.88	48.16	48.04	46.54	50.00	410.35
Paul,M	42.36	56.66	57.08	55.50	53.58	52.78	52.99	57.66	591.51
Geoff,V	33.88	43.60	45.50	44.12	43.68	43.46	42.37	45.57	565.32
Mean	39.04	51.83	52.60	51.78	51.24	50.59	49.51	53.69	653.09
SE	1.84	2.43	2.13	1.91	1.81	1.69	1.94	2.29	47.41

MVC BALLISTIC ARM AG

PRE TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Rob,A	0.88	0.73	0.83	0.88	0.77	0.96	0.84
Colin,M	0.43	0.82	0.75	0.76	0.69	0.90	0.73
Morgan,L	0.57	0.74	0.74	0.73	0.79	0.64	0.70
Kevin,H	1.27	1.48	1.56	1.63	1.65	1.69	1.55
Mark,H	0.70	0.82	0.90	0.95	0.96	0.84	0.86
Todd,A	0.45	0.50	0.56	0.57	0.58	0.70	0.56
Jeremy,M	0.47	0.62	0.66	0.75	0.69	0.92	0.69
Paul,M	0.59	0.64	0.71	0.71	0.74	0.65	0.68
Geoff,V	0.72	0.71	1.29	0.63	0.25	0.38	0.66
Mean	0.68	0.78	0.89	0.85	0.79	0.85	0.80
SE	0.09	0.10	0.12	0.11	0.13	0.13	0.10

POST TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Rob,A	0.74	0.86	0.88	0.88	0.94	1.09	0.90
Colin,M	1.20	1.05	1.21	1.33	1.24	1.24	1.21
Morgan,L	0.68	0.59	0.76	0.74	0.79	0.77	0.72
Kevin,H	0.91	0.93	1.02	1.00	1.23	1.07	1.03
Mark,H	0.77	0.81	0.93	0.85	0.89	0.93	0.86
Todd,A	0.41	0.56	0.52	0.53	0.57	0.56	0.53
Jeremy,M	1.03	1.00	0.92	0.87	1.04	1.15	1.00
Paul,M	0.97	1.08	0.94	1.26	1.22	1.29	1.13
Geoff,V	0.46	0.44	0.49	0.44	0.50	0.39	0.46
Mean	0.80	0.82	0.85	0.88	0.94	0.94	0.87
SE	0.09	0.08	0.08	0.10	0.10	0.11	0.09

MVC BALLISTIC ARM ANT

PRE TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Rob,A	0.15	0.15	0.15	0.14	0.16	0.15	0.15
Colin,M	0.05	0.04	0.03	0.03	0.06	0.04	0.04
Morgan,L	0.20	0.18	0.22	0.23	0.21	0.27	0.22
Kevin,H	0.07	0.07	0.08	0.10	0.11	0.10	0.09
Mark,H	0.14	0.18	0.19	0.20	0.19	0.17	0.18
Todd,A	0.15	0.18	0.19	0.20	0.20	0.24	0.19
Jeremy,M	0.21	0.25	0.24	0.27	0.22	0.27	0.24
Paul,M	0.06	0.06	0.07	0.08	0.09	0.09	0.07
Geoff,V	0.23	0.29	0.03	0.55	0.11	0.25	0.24
Mean	0.14	0.16	0.13	0.20	0.15	0.18	0.16
SE	0.02	0.03	0.03	0.05	0.02	0.03	0.03

POST TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Rob,A	0.10	0.15	0.18	0.17	0.17	0.22	0.16
Colin,M	0.09	0.12	0.11	0.13	0.14	0.13	0.12
Morgan,L	0.17	0.24	0.31	0.32	0.30	0.34	0.28
Kevin,H	0.06	0.06	0.06	0.08	0.10	0.09	0.07
Mark,H	0.09	0.11	0.12	0.13	0.13	0.14	0.12
Todd,A	0.17	0.19	0.17	0.17	0.21	0.19	0.18
Jeremy,M	0.10	0.16	0.16	0.15	0.18	0.19	0.16
Paul,M	0.05	0.06	0.06	0.06	0.06	0.07	0.06
Geoff,V	0.32	0.28	0.31	0.38	0.39	0.34	0.34
Mean	0.13	0.15	0.16	0.18	0.19	0.19	0.17
SE	0.03	0.03	0.03	0.04	0.04	0.03	0.03

MVC **BALLISTIC** **ANT/AG**

PRE TEST

Subjects	0.0-0.5 (s)	0.5-1.0 (s)	1.0-1.5 (s)	1.5-2.0 (s)	2.0-2.5 (s)	2.5-3.0 (s)	0.0-3.0 (s)
Rob,A	0.17	0.21	0.19	0.16	0.20	0.16	0.18
Colin,M	0.12	0.15	0.14	0.14	0.19	0.15	0.15
Morgan,L	0.29	0.25	0.26	0.27	0.27	0.36	0.28
Kevin,H	0.16	0.15	0.15	0.16	0.17	0.16	0.16
Mark,H	0.21	0.21	0.21	0.21	0.20	0.21	0.21
Todd,A	0.26	0.30	0.27	0.29	0.29	0.29	0.28
Jeremy,M	0.26	0.31	0.27	0.30	0.24	0.29	0.28
Paul,M	0.10	0.09	0.10	0.11	0.12	0.14	0.11
Geoff,V	0.25	0.30	0.20	0.36	0.32	0.34	0.30
Mean	0.20	0.22	0.20	0.22	0.22	0.23	0.20
SE	0.02	0.03	0.02	0.03	0.02	0.03	0.02

POST TEST

Subjects	0.0-0.5 (s)	0.5-1.0 (s)	1.0-1.5 (s)	1.5-2.0 (s)	2.0-2.5 (s)	2.5-3.0 (s)	0.0-3.0 (s)
Rob,A	0.13	0.17	0.20	0.19	0.18	0.20	0.18
Colin,M	0.07	0.11	0.09	0.10	0.11	0.11	0.10
Morgan,L	0.25	0.30	0.31	0.34	0.30	0.35	0.31
Kevin,H	0.16	0.16	0.16	0.18	0.18	0.18	0.17
Mark,H	0.12	0.13	0.13	0.15	0.15	0.15	0.14
Todd,A	0.35	0.29	0.28	0.28	0.31	0.27	0.30
Jeremy,M	0.10	0.16	0.17	0.18	0.17	0.16	0.16
Paul,M	0.16	0.15	0.16	0.15	0.15	0.16	0.16
Geoff,V	0.39	0.33	0.32	0.31	0.32	0.33	0.33
Mean	0.19	0.20	0.20	0.21	0.21	0.21	0.20
SE	0.04	0.03	0.03	0.03	0.03	0.03	0.03

MVC BALLISTIC + RESISTANCE ARM TORQUE

PRE TEST

Subjects	0.0-0.5 (s) N.m	0.5-1.0 (s) N.m	1.0-1.5 (s) N.m	1.5-2.0 (s) N.m	2.0-2.5 (s) N.m	2.5-3.0 (s) N.m	0.0-3.0 (s) N.m	PT N.m	MRTD N.m.s
Rob,A	29.02	40.02	38.80	38.86	39.04	38.66	37.40	41.24	434.79
Colin,M	37.46	50.54	50.40	49.22	47.96	48.10	47.28	50.92	703.70
Morgan,L	28.28	42.88	48.46	48.78	47.06	46.52	43.66	49.38	527.34
Kevin,H	28.58	39.70	40.02	41.84	41.60	40.32	38.68	42.54	350.54
Mark,H	37.70	54.44	54.98	54.22	53.18	52.52	51.17	55.11	470.15
Todd,A	28.98	49.02	50.92	55.08	58.24	60.12	50.39	61	430.87
Jeremy,M	30.56	46.88	47.84	47.26	47.48	47.64	44.61	48.46	391.58
Paul,M	36.58	53.92	54.60	53.44	52.72	52.72	50.66	55.06	499.40
Geoff,V	24.34	31.78	31.00	30.30	29.86	28.72	29.33	42.6	479.76
Mean	31.28	45.46	46.34	46.56	46.35	46.15	43.69	49.59	476.46
SE	1.69	2.65	2.85	2.90	3.01	3.26	2.60	2.38	35.73

POST TEST

Subjects	0.0-0.5 (s) N.m	0.5-1.0 (s) N.m	1.0-1.5 (s) N.m	1.5-2.0 (s) N.m	2.0-2.5 (s) N.m	2.5-3.0 (s) N.m	0.0-3.0 (s) N.m	PT N.m	MRTD N.m.s
Rob,A	33.32	48.86	48.82	47.02	46.92	47.68	45.44	49.09	440.03
Colin,M	46.00	64.92	62.48	61.24	60.54	59.42	59.10	64.07	686.24
Morgan,L	25.60	43.54	45.14	42.56	44.76	48.96	41.76	50.00	279.39
Kevin,H	36.30	47.86	50.16	51.32	51.94	51.50	48.18	52.03	573.61
Mark,H	37.40	56.14	57.12	57.32	54.48	53.06	52.59	57.95	603.30
Todd,A	48.40	66.74	67.90	67.36	66.14	65.94	63.75	68.50	801.50
Jeremy,M	36.60	52.70	53.28	52.44	52.18	52.48	49.95	53.62	541.31
Paul,M	45.64	61.22	62.94	63.22	62.16	61.28	59.41	63.54	643.02
Geoff,V	35.26	44.08	43.86	42.44	42.02	42.40	41.68	45.09	708.51
Mean	38.28	54.01	54.63	53.88	53.46	53.64	51.32	55.99	586.32
SE	2.56	3.09	3.00	3.19	2.91	2.60	2.83	2.81	54.85

MVC BALLISTIC + RESISTANCE ARM AG

PRE TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Rob,A	0.66	0.67	0.60	0.70	0.67	0.80	0.68
Colin,M	0.85	0.95	0.86	1.01	0.93	1.23	0.97
Morgan,L	1.19	1.74	1.54	1.68	1.46	1.54	1.53
Kevin,H	0.48	0.46	0.58	0.67	0.58	0.61	0.56
Mark,H	0.86	1.39	1.37	1.56	1.48	1.53	1.36
Todd,A	0.32	0.34	0.39	0.41	0.45	0.45	0.39
Jeremy,M	0.68	0.76	0.88	0.95	0.76	0.84	0.81
Paul,M	0.47	0.45	0.49	0.43	0.51	0.44	0.46
Geoff,V	0.50	0.39	0.34	0.39	0.34	0.38	0.39
Mean	0.67	0.79	0.78	0.87	0.80	0.87	0.80
SE	0.09	0.17	0.15	0.17	0.15	0.16	0.15

POST TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Rob,A	0.58	0.67	0.84	0.22	1.60	1.09	0.83
Colin,M	0.76	0.66	0.73	0.70	0.79	0.91	0.76
Morgan,L	0.46	0.56	0.64	0.65	0.81	0.77	0.65
Kevin,H	0.70	0.78	0.89	1.00	1.10	0.87	0.89
Mark,H	0.69	1.09	1.12	1.10	1.10	0.85	0.99
Todd,A	0.41	0.46	0.47	0.46	0.44	0.49	0.46
Jeremy,M	0.59	0.65	0.61	0.64	1.28	0.96	0.79
Paul,M	1.03	1.26	1.40	1.42	1.57	1.64	1.39
Geoff,V	1.06	0.82	0.75	0.79	0.82	0.80	0.84
Mean	0.70	0.77	0.83	0.78	1.06	0.93	0.84
SE	0.08	0.09	0.10	0.13	0.14	0.11	0.09

MVC **BALLISTIC + RESISTANCE ARM** **ANT**

PRE TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Rob,A	0.15	0.14	0.17	0.18	0.18	0.17	0.17
Colin,M	0.19	0.23	0.30	0.37	0.31	0.37	0.30
Morgan,L	0.21	0.24	0.23	0.17	0.26	0.25	0.23
Kevin,H	0.06	0.07	0.08	0.10	0.10	0.11	0.09
Mark,H	0.12	0.19	0.25	0.23	0.25	0.27	0.22
Todd,A	0.11	0.12	0.15	0.18	0.20	0.23	0.17
Jeremy,M	0.17	0.23	0.24	0.25	0.26	0.30	0.24
Paul,M	0.09	0.10	0.12	0.11	0.12	0.14	0.11
Geoff,V	0.28	0.29	0.28	0.30	0.33	0.33	0.30
Mean	0.15	0.18	0.20	0.21	0.23	0.24	0.20
SE	0.02	0.03	0.03	0.03	0.03	0.03	0.03

POST TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Rob,A	0.12	0.17	0.21	0.16	0.24	0.27	0.19
Colin,M	0.19	0.23	0.29	0.27	0.29	0.33	0.27
Morgan,L	0.10	0.12	0.13	0.18	0.24	0.28	0.17
Kevin,H	0.05	0.07	0.07	0.08	0.08	0.08	0.07
Mark,H	0.11	0.13	0.15	0.17	0.17	0.13	0.15
Todd,A	0.17	0.16	0.16	0.17	0.18	0.22	0.18
Jeremy,M	0.18	0.28	0.26	0.07	0.32	0.55	0.28
Paul,M	0.07	0.08	0.08	0.09	0.11	0.12	0.09
Geoff,V	0.17	0.18	0.24	0.23	0.22	0.19	0.20
Mean	0.13	0.16	0.18	0.16	0.21	0.24	0.18
SE	0.02	0.02	0.03	0.02	0.03	0.05	0.02

MVC BALLISTIC + RESISTANCE ANT/AG

PRE TEST

Subjects	0.0-0.5 (s)	0.5-1.0 (s)	1.0-1.5 (s)	1.5-2.0 (s)	2.0-2.5 (s)	2.5-3.0 (s)	0.0-3.0 (s)
Rob,A	0.23	0.22	0.28	0.26	0.28	0.21	0.25
Colin,M	0.22	0.25	0.35	0.36	0.33	0.30	0.30
Morgan,L	0.18	0.14	0.15	0.10	0.18	0.16	0.15
Kevin,H	0.13	0.15	0.13	0.15	0.18	0.18	0.15
Mark,H	0.14	0.13	0.18	0.15	0.17	0.17	0.16
Todd,A	0.35	0.36	0.32	0.36	0.37	0.44	0.37
Jeremy,M	0.24	0.30	0.27	0.27	0.35	0.36	0.30
Paul,M	0.18	0.22	0.24	0.26	0.24	0.32	0.24
Geoff,V	0.28	0.34	0.38	0.40	0.41	0.35	0.36
Mean	0.22	0.23	0.26	0.26	0.28	0.28	0.25
SE	0.02	0.03	0.03	0.04	0.03	0.04	0.03

POST TEST

Subjects	0.0-0.5 (s)	0.5-1.0 (s)	1.0-1.5 (s)	1.5-2.0 (s)	2.0-2.5 (s)	2.5-3.0 (s)	0.0-3.0 (s)
Rob,A	0.13	0.17	0.20	0.19	0.18	0.20	0.18
Colin,M	0.07	0.11	0.09	0.10	0.11	0.11	0.10
Morgan,L	0.25	0.30	0.31	0.34	0.29	0.34	0.30
Kevin,H	0.16	0.16	0.16	0.18	0.18	0.18	0.17
Mark,H	0.12	0.13	0.13	0.15	0.15	0.15	0.14
Todd,A	0.35	0.29	0.28	0.28	0.31	0.29	0.30
Jeremy,M	0.10	0.16	0.17	0.18	0.17	0.16	0.16
Paul,M	0.16	0.15	0.16	0.15	0.15	0.16	0.16
Geoff,V	0.29	0.33	0.32	0.41	0.49	0.46	0.38
Mean	0.18	0.20	0.20	0.22	0.23	0.23	0.21
SE	0.03	0.03	0.03	0.04	0.04	0.04	0.03

MVC CONTROL ARM TORQUE

PRE TEST

Subjects	0.0-0.5 (s) N.m	0.5-1.0 (s) N.m	1.0-1.5 (s) N.m	1.5-2.0 (s) N.m	2.0-2.5 (s) N.m	2.5-3.0 (s) N.m	0.0-3.0 (s) N.m	PT N.m	MRTD N.m.s
Ian,T	37.76	53.28	56.24	55.46	55.18	50.90	51.47	57.18	439.16
Neal,K	27.18	39.94	41.24	42.24	42.10	42.76	39.24	42.30	361.46
Craig,H	18.48	34.22	37.78	36.62	35.16	37.72	33.33	38.20	219.58
Darcy.P	18.38	28.82	31.36	32.46	31.52	31.64	29.03	32.56	210.41
Greg,K	25.94	38.78	41.78	42.28	42.72	38.88	38.40	42.89	364.51
Rob,H	30.20	52.80	52.66	51.40	49.72	47.30	47.35	53.33	322.17
Lee,B	31.60	36.64	35.16	31.46	28.10	27.00	31.66	40.85	695.85
Paul,H	32.50	46.36	46.90	46.34	45.28	45.28	43.78	47.11	488.05
Jay,M	37.44	50.36	49.80	49.22	48.44	44.90	46.69	50.77	647.39
Brad,M	28.92	39.42	39.12	38.66	37.14	35.16	36.40	39.74	472.34
Mean	28.84	42.06	43.20	42.61	41.54	40.15	39.74	44.49	422.09
SE	2.23	2.76	2.66	2.67	2.85	2.48	2.47	2.51	53.94

POST TEST

Subjects	0.0-0.5 (s) N.m	0.5-1.0 (s) N.m	1.0-1.5 (s) N.m	1.5-2.0 (s) N.m	2.0-2.5 (s) N.m	2.5-3.0 (s) N.m	0.0-3.0 (s) N.m	PT N.m	MRTD N.m.s
Ian,T	37.36	55.76	54.92	53.86	52.26	51.70	50.98	56.60	420.83
Neal,K	26.30	47.18	49.68	51.10	51.10	50.72	46.01	51.40	183.78
Craig,H	19.90	38.00	43.96	44.04	38.00	49.12	38.84	44.34	182.47
Darcy.P	19.22	32.58	32.80	30.24	32.42	33.16	30.07	33.29	240.97
Greg,K	31.54	44.82	44.06	43.64	44.60	44.04	42.12	45.04	539.13
Rob,H	35.62	52.30	51.12	50.88	49.94	49.36	48.20	52.36	353.16
Lee,B	36.74	46.88	48.04	49.14	48.48	47.24	46.09	49.52	565.76
Paul,H	17.16	40.56	44.06	43.94	43.36	41.84	38.49	44.22	161.08
Jay,M	41.08	52.64	53.38	51.38	50.12	52.12	50.12	54.19	706.32
Brad,M	30.26	42.96	41.56	42.26	39.96	37.64	39.11	43.36	672.27
Mean	29.52	45.37	46.36	46.05	45.02	45.69	43.00	47.43	402.58
SE	2.83	2.39	2.17	2.29	2.19	2.14	2.17	2.27	69.73

MVC CONTROL ARM AG

PRE TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Ian,T	0.27	0.29	0.35	0.33	0.35	0.28	0.31
Neal,K	0.48	0.56	0.68	0.80	0.65	0.80	0.66
Craig,H	0.41	0.59	0.62	0.54	0.59	0.66	0.57
Darcy.P	0.40	0.44	0.42	0.41	0.37	0.50	0.43
Greg,K	0.47	0.49	0.49	0.61	0.56	0.50	0.52
Rob,H	0.43	0.51	0.45	0.54	0.50	0.54	0.49
Lee,B	1.69	1.96	2.00	2.34	1.87	1.70	1.93
Paul,H	0.85	1.14	0.95	0.79	0.94	0.84	0.92
Jay,M	0.47	0.44	0.46	0.48	0.43	0.50	0.46
Brad,M	0.45	0.76	0.87	0.90	0.88	0.83	0.78
Mean	0.59	0.72	0.73	0.77	0.71	0.71	0.71
SE	0.14	0.16	0.16	0.19	0.15	0.13	0.15

POST TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Ian,T	0.25	0.29	0.32	0.33	0.36	0.36	0.32
Neal,K	0.38	0.45	0.47	0.50	0.48	0.45	0.45
Craig,H	0.49	0.82	0.99	0.97	0.89	0.84	0.83
Darcy.P	0.36	0.35	0.34	0.33	0.45	0.51	0.39
Greg,K	0.41	0.49	0.49	0.50	0.59	0.44	0.49
Rob,H	1.15	1.31	1.26	1.22	1.35	1.36	1.28
Lee,B	1.68	1.72	2.04	1.93	1.64	2.20	1.87
Paul,H	0.44	0.72	0.76	0.83	0.66	0.79	0.70
Jay,M	0.49	0.46	0.43	0.42	0.40	0.42	0.44
Brad,M	0.56	0.50	0.57	0.51	0.56	0.62	0.55
Mean	0.62	0.71	0.77	0.76	0.74	0.80	0.73
SE	0.15	0.15	0.18	0.17	0.14	0.19	0.02

MVC CONTROL ARM ANT

PRE TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Ian,T	0.08	0.11	0.15	0.15	0.17	0.17	0.14
Neal,K	0.06	0.07	0.10	0.11	0.13	0.13	0.10
Craig,H	0.08	0.12	0.12	0.12	0.13	0.17	0.12
Darcy.P	0.04	0.06	0.07	0.09	0.09	0.10	0.08
Greg,K	0.06	0.08	0.10	0.12	0.12	0.11	0.10
Rob,H	0.07	0.08	0.09	0.11	0.10	0.10	0.09
Lee,B	0.16	0.14	0.15	0.20	0.16	0.18	0.16
Paul,H	0.06	0.11	0.12	0.13	0.12	0.10	0.11
Jay,M	0.07	0.07	0.07	0.08	0.09	0.08	0.08
Brad,M	0.10	0.11	0.11	0.11	0.11	0.11	0.11
Mean	0.08	0.10	0.11	0.12	0.12	0.12	0.11
SE	0.01	0.01	0.01	0.01	0.01	0.01	0.01

POST TEST

Subjects	0.0-0.5 (s) mV	0.5-1.0 (s) mV	1.0-1.5 (s) mV	1.5-2.0 (s) mV	2.0-2.5 (s) mV	2.5-3.0 (s) mV	0.0-3.0 (s) mV
Ian,T	0.07	0.09	0.13	0.17	0.16	0.17	0.13
Neal,K	0.05	0.07	0.08	0.11	0.13	0.13	0.09
Craig,H	0.20	0.19	0.12	0.12	0.11	0.10	0.14
Darcy.P	0.04	0.05	0.05	0.06	0.06	0.09	0.06
Greg,K	0.07	0.10	0.10	0.11	0.12	0.12	0.10
Rob,H	0.14	0.18	0.15	0.17	0.20	0.17	0.17
Lee,B	0.19	0.16	0.17	0.15	0.15	0.18	0.17
Paul,H	0.04	0.07	0.07	0.07	0.06	0.07	0.06
Jay,M	0.06	0.05	0.06	0.06	0.06	0.06	0.06
Brad,M	0.11	0.14	0.15	0.15	0.13	0.17	0.14
Mean	0.10	0.11	0.11	0.12	0.12	0.13	0.11
SE	0.02	0.02	0.01	0.01	0.02	0.02	0.02

MVC CONTROL ARM ANT/AG

PRE TEST

Subjects	0.0-0.5 (s)	0.5-1.0 (s)	1.0-1.5 (s)	1.5-2.0 (s)	2.0-2.5 (s)	2.5-3.0 (s)	0.0-3.0 (s)
Ian,T	0.22	0.27	0.30	0.29	0.32	0.33	0.29
Neal,K	0.12	0.12	0.15	0.13	0.19	0.17	0.15
Craig,H	0.14	0.16	0.20	0.22	0.22	0.19	0.19
Darcy.P	0.10	0.13	0.17	0.15	0.15	0.21	0.15
Greg,K	0.13	0.16	0.20	0.19	0.22	0.21	0.19
Rob,H	0.16	0.16	0.21	0.20	0.15	0.18	0.18
Lee,B	0.09	0.07	0.07	0.09	0.08	0.10	0.09
Paul,H	0.07	0.09	0.13	0.16	0.12	0.12	0.12
Jay,M	0.15	0.15	0.16	0.16	0.18	0.16	0.16
Brad,M	0.18	0.15	0.12	0.13	0.13	0.13	0.14
Mean	0.14	0.15	0.17	0.17	0.18	0.18	0.16
SE	0.01	0.02	0.02	0.02	0.02	0.02	0.02

POST TEST

Subjects	0.0-0.5 (s)	0.5-1.0 (s)	1.0-1.5 (s)	1.5-2.0 (s)	2.0-2.5 (s)	2.5-3.0 (s)	0.0-3.0 (s)
Ian,T	0.18	0.24	0.32	0.22	0.33	0.32	0.27
Neal,K	0.13	0.15	0.18	0.18	0.27	0.22	0.19
Craig,H	0.16	0.16	0.12	0.12	0.13	0.12	0.14
Darcy.P	0.10	0.14	0.16	0.18	0.14	0.18	0.15
Greg,K	0.18	0.14	0.20	0.18	0.21	0.26	0.19
Rob,H	0.10	0.14	0.12	0.14	0.15	0.13	0.13
Lee,B	0.11	0.09	0.08	0.08	0.09	0.08	0.09
Paul,H	0.10	0.10	0.09	0.08	0.09	0.08	0.09
Jay,M	0.13	0.12	0.14	0.13	0.15	0.14	0.13
Brad,M	0.15	0.21	0.22	0.29	0.23	0.23	0.22
Mean	0.13	0.15	0.16	0.16	0.18	0.18	0.16
SE	0.01	0.02	0.02	0.02	0.03	0.03	0.02

I RM **BALLISTIC ARM**

PRE TEST

Subject:	Wt. lifted	AG IEMG(mV.s)	ANT IEMG(mV.s)	Torque Duration (s)	Agonist Duration (s)	AG IEMG (mV)	Antagonist Duration (s)	ANT EMG (mV)	ANT/AG
Rob,A	15.50	4.83	3.42	5.10	5.10	0.95	5.10	0.17	0.18
Colin,M	18.45	5.17	1.19	4.25	4.25	1.22	4.25	0.07	0.06
Morgan,L	16.50	1.68	1.90	2.32	2.32	0.72	2.32	0.20	0.28
Kevin,H	11.01	2.41	0.89	2.94	2.94	0.82	2.94	0.08	0.09
Mark,H	18.79	2.09	1.96	3.37	3.37	0.62	3.37	0.15	0.23
Todd,A	14.66	1.73	1.46	3.73	3.73	0.46	3.73	0.10	0.21
Jeremy,M	11.65	2.69	2.33	6.45	6.45	0.42	6.45	0.09	0.22
Paul,M	15.55	2.72	1.15	3.03	3.03	0.90	3.03	0.09	0.11
Geoff,V	16.61	1.16	1.79	3.00	3.00	0.39	3.00	0.15	0.38
MEAN	15.41	2.72	1.79	3.80	3.80	0.72	3.80	0.12	0.20
SE	0.95	0.49	0.27	0.46	0.46	0.10	0.46	0.02	0.04

POST TEST

Subject:	Wt. lifted	AG IEMG(mV.s)	ANT IEMG(mV.s)	Torque Duration (s)	Agonist Duration (s)	AG IEMG (mV)	Antagonist Duration (s)	ANT EMG (mV)	ANT/AG
Rob,A	13.75	2.16	1.41	2.83	2.89	0.75	2.89	0.12	0.16
Colin,M	19.30	4.76	1.31	4.02	4.02	1.18	4.02	0.08	0.07
Morgan,L	16.34	1.99	1.41	2.67	2.67	0.74	2.67	0.13	0.18
Kevin,H	13.45	3.45	1.15	3.61	3.61	0.96	3.61	0.08	0.08
Mark,H	17.18	4.90	1.74	4.26	4.26	1.15	4.26	0.10	0.09
Todd,A	16.69	1.62	1.39	3.67	3.67	0.44	3.67	0.09	0.22
Jeremy,M	13.06	2.41	1.88	4.89	4.89	0.49	4.89	0.10	0.19
Paul,M	15.70	4.13	1.41	3.56	3.56	1.16	3.56	0.10	0.09
Geoff,V	16.60	1.14	1.74	2.87	2.87	0.40	2.87	0.15	0.38
MEAN	15.79	2.95	1.49	3.60	3.60	0.81	3.60	0.11	0.16
SE	0.72	0.49	0.08	0.26	0.26	0.11	0.26	0.01	0.04

1 RM **BALLISTIC+RESISTANCE ARM**

PRE TEST

Subject:	Wt. lifted	AG IEMG(mV.s)	ANT IEMG(mV.s)	Torque Duration (s)	Agonist Duration (s)	AG IEMG (mV)	Antagonist Duration (s)	ANT EMG (mV)	ANT/AG
Rob,A	12.75	4.58	4.65	6.56	6.56	0.70	6.56	0.18	0.25
Colin,M	18.47	3.89	2.40	4.03	4.03	0.96	4.03	0.15	0.15
Morgan,L	15.02	3.79	1.35	2.59	2.59	1.46	2.59	0.13	0.09
Kevin,H	12.60	2.32	1.38	4.37	4.37	0.53	4.37	0.08	0.15
Mark,H	18.28	2.84	3.26	3.60	3.60	0.79	3.60	0.23	0.29
Todd,A	18.50	1.09	1.23	3.57	3.57	0.31	3.57	0.09	0.28
Jeremy,M	11.37	4.31	2.46	7.77	7.77	0.55	7.77	0.08	0.14
Paul,M	14.50	2.66	3.04	5.00	5.00	0.53	5.00	0.15	0.29
Geoff,V	11.50	2.25	2.52	4.21	4.21	0.53	4.21	0.15	0.28
MEAN	14.78	3.08	2.48	4.63	4.63	0.71	4.63	0.14	0.20
SE	1.05	0.40	0.39	0.57	0.57	0.12	0.57	0.02	0.04

POST TEST

Subject:	Wt. lifted	AG IEMG(mV.s)	ANT IEMG(mV.s)	Torque Duration (s)	Agonist Duration (s)	AG IEMG (mV)	Antagonist Duration (s)	ANT EMG (mV)	ANT/AG
Rob,A	15.10	5.13	5.62	7.10	7.10	0.72	7.10	0.20	0.27
Colin,M	19.70	2.70	1.70	3.97	3.97	0.68	3.97	0.11	0.16
Morgan,L	19.50	4.72	3.21	3.44	3.44	1.37	3.44	0.23	0.17
Kevin,H	16.00	8.17	3.14	7.16	7.16	1.14	7.16	0.11	0.10
Mark,H	21.00	23.75	13.30	11.36	11.36	2.09	11.36	0.29	0.14
Todd,A	19.70	1.46	1.10	2.92	2.92	0.50	2.92	0.09	0.19
Jeremy,M	14.74	1.94	1.54	4.82	4.82	0.38	4.82	0.08	0.21
Paul,M	18.75	2.85	1.08	2.85	2.85	1.21	2.85	0.09	0.08
Geoff,V	20.50	3.31	1.28	3.23	3.23	1.03	3.23	0.10	0.10
MEAN	18.33	6.00	3.55	5.21	5.21	1.01	5.21	0.15	0.16
SE	0.85	2.46	1.39	1.01	1.01	0.19	1.01	0.03	0.02

1 RM **CONTROL ARM**

PRE TEST

Subject:	Wt. lifted	AG IEMG(mV.s)	ANT IEMG(mV.s)	Torque Duration (s)	Agonist Duration (s)	AG IEMG (mV)	Antagonist Duration (s)	ANT IEMG (mV)	ANT/AG
Ian,T	15.90	1.62	1.10	2.72	2.72	0.59	2.72	0.10	0.17
Neal,K	11.23	4.06	2.58	4.31	4.31	0.94	4.31	0.15	0.16
Craig,H	12.50	1.75	1.02	2.15	2.15	0.82	2.15	0.12	0.15
Darcy,P	11.00	1.55	2.05	4.21	4.21	0.37	4.21	0.12	0.33
Greg,K	14.30	2.76	1.56	3.26	3.26	0.85	3.26	0.12	0.14
Rob,H	13.83	2.40	1.45	2.76	2.76	0.87	2.76	0.13	0.15
Lee,B	14.20	2.54	1.02	3.01	3.01	0.84	3.01	0.09	0.10
Paul,H	14.52	3.76	2.00	4.87	4.87	0.77	4.87	0.10	0.13
Jay,M	16.25	2.31	1.00	2.73	2.73	0.85	2.73	0.09	0.11
Brad,M	12.46	1.30	1.57	2.61	2.61	0.50	2.61	0.15	0.30
MEAN	13.62	2.41	1.54	3.26	3.26	0.74	3.26	0.12	0.17
SE	0.60	0.31	0.18	0.30	0.30	0.06	0.30	0.01	0.03

POST TEST

Subject:	Wt. lifted	AG IEMG(mV.s)	ANT IEMG(mV.s)	Torque Duration (s)	Agonist Duration (s)	AG IEMG (mV)	Antagonist Duration (s)	ANT IEMG (mV)	ANT/AG
Ian,T	14.20	3.44	1.26	3.59	3.59	0.96	3.59	0.09	0.09
Neal,K	13.52	3.65	2.51	4.79	4.79	0.76	4.79	0.13	0.17
Craig,H	15.17	4.27	2.14	4.56	4.56	0.93	4.56	0.12	0.13
Darcy,P	9.80	1.68	1.81	5.43	5.43	0.31	5.43	0.08	0.27
Greg,K	13.30	2.06	1.92	3.54	3.54	0.58	3.54	0.14	0.23
Rob,H	12.30	2.02	2.46	4.02	4.02	0.50	4.02	0.15	0.30
Lee,B	14.93	2.51	1.37	4.37	4.37	0.57	4.37	0.08	0.14
Paul,H	14.22	4.25	1.73	5.54	5.54	0.77	5.54	0.08	0.10
Jay,M	18.35	2.12	1.16	3.50	3.50	0.61	3.50	0.08	0.14
Brad,M	12.50	1.42	1.76	3.48	3.48	0.41	3.48	0.13	0.31
MEAN	13.83	2.74	1.81	4.28	4.28	0.64	4.28	0.11	0.19
SE	0.74	0.35	0.16	0.26	0.26	0.07	0.26	0.01	0.03

FIBRE AREA BALL + RES FIBRE AREA BALL + RES
PRE TEST POST TEST

NAME	SLOW	FOG	FG	NAME	SLOW	FOG	FG
Colin, M	3348	6555	5273	Colin, M	4290	7326	6644
Jeremy, M	3810	6005	5636	Jeremy, M	3211	6854	6385
Kevin, H	4506	7117	6774	Kevin, H	5444	9168	8538
Mark, H	2198	5951	5461	Mark, H	2319	5312	5209
Morgan, L	3824	6063	5772	Morgan, L	3895	6666	6443
Paul, M	3202	6128	5825	Paul, M	2950	7683	7034
Todd, A	4130	7249	6368	Todd, A	5278	9238	8727
Geoff, V	3089	5284	5121	Geof, V	3440	5865	5729
Rob, A	3426	5310	5203	Rob, A	3631	5670	5905
Mean	3504	6185	5715	Mean	3829	7087	6735
SE	237	244	195	SE	366	504	425

FIBRE AREA BALL FIBRE AREA BALL
PRE TEST POST TEST

NAME	SLOW	FOG	FG	NAME	SLOW	FOG	FG
Colin, M	3834	7515	6807	Colin, M	3763	7481	6854
Jeremy, M	2339	5193	5158	Jeremy, M	2486	4999	4670
Kevin, H	2584	4771	4384	Kevin, H	3151	4634	4897
Mark, H	2424	5684	5749	Mark, H	2159	5588	5661
Morgan, L	3245	6088	6329	Morgan, L	3273	5739	5305
Paul, M	3364	7855	6988	Paul, M	3985	9674	8553
Todd, A	3552	6252	5624	Todd, A	3211	5252	4942
Geoff, V	2778	5573	4728	Geof, V	3461	6001	5539
Rob, A	3369	4141	5193	Rob, A	4314	4466	5432
Mean	3054	5897	5662	Mean	3311	5982	5762
SE	189	426	319	SE	242	582	433

FIBRE AREA CON
PRE TEST

FIBRE AREA CON
POST TEST

NAME	SLOW	FOG	FG	NAME	SLOW	FOG	FG
Rob, H	3061	5102	5306	Rob, H	2895	5058	4968
Paul, H	4950	6195	6225	Paul, H	4548	6095	5934
Neal, K	2175	4689	3898	Neal, K	2329	4681	4177
Jay, M	3988	5474	4975	Jay, M	3466	5407	4771
Lee, B	3987	5473	4973	Lee, B	3466	5406	477
Ian, T	3991	7024	7579	Ian, T	3474	6388	7023
Greg,K	2982	5078	4076	Greg,K	3064	5208	4610
Darcy, P	2873	5692	5384	Darcy, P	2398	4919	4702
Craig, H	2959	3940	3380	Craig, H	3566	4662	3990
Brad, M	3263	6405	6325	Brad, M	3307	6970	6510
Mean	3423	5507	5212	Mean	3251	5479	4716
SE	266	296	422	SE	213	256	597

% FIBRE NUMBER BALLISTIC ARM

PRE TEST

Name	SLOW	FOG	FG	UNCLASS	FT
Morgan, L	0.43	0.28	0.21	0.08	0.57
Geoff, V	0.31	0.14	0.32	0.22	0.69
Todd, A	0.29	0.24	0.27	0.21	0.71
Kevin, H	0.37	0.24	0.28	0.11	0.61
Mark, H	0.41	0.24	0.22	0.13	0.59
Collin, M	0.44	0.27	0.25	0.05	0.56
Paul, M	0.40	0.35	0.17	0.07	0.60
Jeremy, M	0.43	0.38	0.15	0.04	0.57
Rob, A	0.40	0.27	0.24	0.08	0.60

Mean	0.39	0.27	0.23	0.11	0.61
SE	0.02	0.02	0.02	0.02	0.02

POST TEST

Name	SLOW	FOG	FG	UNCLASS	FT
Morgan, L	0.36	0.32	0.26	0.07	0.64
Geoff, V	0.30	0.22	0.27	0.21	0.70
Todd, A	0.27	0.32	0.22	0.19	0.73
Kevin, H	0.46	0.25	0.19	0.09	0.54
Mark, H	0.48	0.24	0.16	0.13	0.52
Collin, M	0.44	0.26	0.20	0.10	0.56
Paul, M	0.42	0.33	0.13	0.12	0.58
Jeremy, M	0.34	0.32	0.24	0.11	0.66
Rob, A	0.33	0.31	0.31	0.05	0.67

Mean	0.38	0.28	0.22	0.12	0.62
SE	0.03	0.01	0.02	0.02	0.03

% FIBRE NUMBER BALLISTIC + RESISTANCE ARM

PRE TEST

Name	SLOW	FOG	FG	UNCLASS	FT
Morgan, L	0.43	0.28	0.21	0.08	0.57
Geoff, V	0.37	0.30	0.23	0.10	0.63
Todd, A	0.35	0.36	0.22	0.07	0.65
Kevin, H	0.40	0.30	0.21	0.08	0.60
Mark, H	0.39	0.24	0.21	0.16	0.61
Collin, M	0.45	0.22	0.20	0.13	0.55
Paul, M	0.42	0.23	0.28	0.07	0.58
Jeremy, M	0.35	0.28	0.19	0.18	0.65
Rob, A	0.34	0.27	0.26	0.13	0.66

Mean	0.39	0.28	0.22	0.11	0.61
SE	0.01	0.02	0.01	0.01	0.01

POST TEST

Name	SLOW	FOG	FG	UNCLASS	FT
Morgan, L	0.45	0.28	0.17	0.10	0.55
Geoff, V	0.36	0.38	0.16	0.10	0.64
Todd, A	0.32	0.30	0.22	0.15	0.68
Kevin, H	0.34	0.28	0.23	0.15	0.66
Mark, H	0.50	0.23	0.13	0.14	0.50
Collin, M	0.44	0.24	0.16	0.16	0.56
Paul, M	0.40	0.33	0.23	0.04	0.60
Jeremy, M	0.40	0.25	0.20	0.15	0.70
Rob, A	0.46	0.21	0.20	0.13	0.54

Mean	0.41	0.28	0.19	0.12	0.60
SE	0.02	0.02	0.01	0.01	0.02

% FIBRE NUMBER CONTROL ARM

PRE TEST

Name	SLOW	FOG	FG	UNCLASS	FT
Jay, M	0.29	0.33	0.28	0.10	0.71
Paul, H	0.47	0.28	0.18	0.07	0.53
Greg, K	0.31	0.34	0.26	0.08	0.69
Lee, B	0.39	0.27	0.21	0.13	0.61
Ian, T	0.40	0.29	0.24	0.08	0.60
Darcy, P	0.36	0.26	0.26	0.12	0.64
Craig, H	0.35	0.26	0.26	0.14	0.65
Neal, K	0.42	0.26	0.21	0.11	0.58
Brad, M	0.35	0.30	0.22	0.13	0.65
Rob, H	0.42	0.21	0.26	0.11	0.58

Mean	0.38	0.28	0.24	0.12	0.62
SE	0.02	0.01	0.01	0.02	0.02

POST TEST

Name	SLOW	FOG	FG	UNCLASS	FT
Jay, M	0.26	0.28	0.36	0.10	0.74
Paul, H	0.45	0.33	0.15	0.07	0.55
Greg, K	0.35	0.31	0.23	0.10	0.65
Lee, B	0.36	0.29	0.24	0.11	0.64
Ian, T	0.44	0.28	0.23	0.06	0.56
Darcy, P	0.38	0.24	0.25	0.13	0.62
Craig, H	0.32	0.25	0.28	0.15	0.68
Neal, K	0.41	0.27	0.24	0.09	0.59
Brad, M	0.41	0.32	0.20	0.08	0.59
Rob, H	0.44	0.21	0.27	0.08	0.56

Mean	0.38	0.28	0.25	0.10	0.62
SE	0.02	0.01	0.02	0.01	0.02

Appendix 2

ANOVA Tables & Post Hoc Tests

CONTRACTILE PROPERTIES   BALLISTIC ARM

```
Summary of all Effects; PT
1-TIME
              df        MS        df        MS
            Effect    Effect    Error     Error         F        p-level
1             1       0.3872      8     4.298263   0.090083   0.771723

Summary of all Effects; TPT
1-TIME
              df        MS        df        MS
            Effect    Effect    Error     Error         F        p-level
1             1     17.78067      8     7.083535   2.510141   0.151775


Summary of all Effects; MRTD
1-TIME
              df        MS        df        MS
            Effect    Effect    Error     Error         F        p-level
1             1     1677.17       8     2407.41    0.69667    0.428124


Summary of all Effects;  MRTR
1-TIME
              df        MS        df        MS
            Effect    Effect    Error     Error         F        p-level
1             1     1017.907      8     915.665    1.111659   0.322521

Summary of all Effects; TTI
1-TIME
              df        MS        df        MS
            Effect    Effect    Error     Error         F        p-level
1             1     0.071568      8     0.098712   0.72502    0.419259

Summary of all Effects; TTI 1/2 R
1-TIME
              df        MS        df        MS
            Effect    Effect    Error     Error         F        p-level
1             1     0.00732       8     0.048521   0.150874   0.707834

Summary of all Effects; 1/2R
1-TIME
              df        MS        df        MS
            Effect    Effect    Error     Error         F        p-level
1             1     55.02005      8     30.94656   1.777905   0.219123
```

Summary of all Effects; PT
1-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	7.986672	8	1.277122	6.253647	0.0369

Summary of all Effects; TPT
1-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.299022	8	17.14289	0.017443	0.898189

Summary of all Effects; MRTD
1-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	11448.87	8	1892.865	6.048437	0.039358

Summary of all Effects; MRTR
1-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	3785.66	8	533.8331	7.091467	0.028673

Summary of all Effects;TTI
1-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.14045	8	0.04265	3.293083	0.10712

Summary of all Effects; TTI 1/2 R
1-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.058939	8	0.016551	3.560963	0.09586

Summary of all Effects; 1/2R
1-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	10.24536	8	45.58472	0.224754	0.648111

CONTRACTILE PROPERTIES CONTROL ARM

```
Summary of all Effects; PT
1-TIME
                df        MS        df        MS
              Effect    Effect    Error     Error        F        p-level
1               1      0.21218      9      0.703158  0.301753   0.59615

Summary of all Effects; TPT
1-TIME
                df        MS        df        MS
              Effect    Effect    Error     Error        F        p-level
1               1     7.454205      9      18.26636  0.408084  0.538859

Summary of all Effects; MRTD
1-TIME
                df        MS        df        MS
              Effect    Effect    Error     Error        F        p-level
1               1     3652.023      9      1309.614  2.788625  0.129275

Summary of all Effects; MRTR
1-TIME
                df        MS        df        MS
              Effect    Effect    Error     Error        F        p-level
1               1     1110.497      9      261.2198  4.251198  0.069273

Summary of all Effects; TTI
1-TIME
                df        MS        df        MS
              Effect    Effect    Error     Error        F        p-level
1               1      0.00968      9      0.015813  0.612142  0.454075

Summary of all Effects; TTI 1/2 R
1-TIME
                df        MS        df        MS
              Effect    Effect    Error     Error        F        p-level
1               1     0.002205      9      0.013716   0.16076   0.69781

Summary of all Effects; 1/2R
1-TIME
                df        MS        df        MS
              Effect    Effect    Error     Error        F        p-level
1               1     118.4871      9      26.80213   4.42081  0.064847
```

Summary of all Effects; MT (3 TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.0184	8	0.0613	0.3	0.599
2	1	0.2896	8	0.0284	10.18	0.013
12	1	0.0131	8	0.056	0.234	0.642

Summary of all Effects; PEAK VELOCITY (3 TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	851.67	8	1023.7	0.832	0.388
2	1	10106	8	1758.7	5.746	0.043
12	1	1504.1	8	696.68	2.159	0.18

Summary of all Effects; PEAK ACC (TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	25849	8	265496	0.097	0.763
2	1	5E+06	8	603904	8.381	0.02
12	1	136161	8	151280	0.9	0.371

Summary of all Effects; PEAK TORQUE (3 TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.0828	8	3.1885	0.026	0.876
2	1	136.6	8	2.1163	64.55	4E-05
12	1	0.0012	8	0.5936	0.002	0.965

Summary of all Effects; TIME TO PEAK TORQUE (3 TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.0006	8	0.0001	4.753	0.061
2	1	0.0012	8	7E-05	16.43	0.004
12	1	0.0001	8	7E-05	1.529	0.251

Summary of all Effects; MRTD (3 TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.6751	8	12425	5E-05	0.994
2	1	501636	8	3892.5	128.9	3E-06
12	1	2.2118	8	4776.4	5E-04	0.983

BALLISTIC TEST **TRAINED ARM (3 TRIALS)**

Summary of all Effects; PEAK POWER (3 TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.6751	8	12425	5E-05	0.994
2	1	501636	8	3892.5	128.9	3E-06
12	1	2.2118	8	4776.4	5E-04	0.983

Summary of all Effects; AG EMG (3 TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.0095	8	0.0526	0.182	0.681
2	1	0.1697	8	0.0172	9.895	0.014
12	1	0.0049	8	0.0101	0.485	0.506

Summary of all Effects; ANT EMG (3 TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.0005	8	0.0011	0.445	0.524
2	1	0.0036	8	0.0009	4.01	0.045
12	1	8E-08	8	0.0003	3E-04	0.987

Summary of all Effects; ANT/AG EMG (3 TRIALS)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.0004	8	0.002	0.198	0.668
2	1	1E-06	8	0.0011	9E-04	0.977
12	1	5E-06	8	0.0022	0.002	0.964

BALLISTIC TEST **CONTROL ARM (AVERAGE OF 3 TRIALS)**

```
Summary of all Effects; MT (3TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     1E-04     9     1E-04   1.176   0.306

Summary of all Effects;  PEAK VELOCITY (3TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     1839      9     128.4   14.32   0.004

Summary of all Effects; PEAK ACC.  (3TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     69129     9     80902   0.854   0.052

Summary of all Effects; PEAK TORQUE (3TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     1.349     9     0.31    4.346   0.067

Summary of all Effects; TIME TO PEAK TORQUE (3TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     6E-04     9     0.003    0.2    0.036

Summary of all Effects;  MRTD (3TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     29258     9     1846    15.85   0.003

Summary of all Effects;  PEAK POWER (3TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     1E+06     9     85651   16.83   0.003

Summary of all Effects; AG EMG (3TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     0.001     9     0.007   0.177   0.684

Summary of all Effects;  ANT EMG (3TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     2E-04     9     9E-05    2.4    0.156

Summary of all Effects; ANT/AG EMG (3 TRAILS)
1-TIME
          df      MS      df      MS
        Effect  Effect  Error   Error      F    p-level
1         1     5E-04     9     5E-04   0.842   0.383
```

MVC TRAINED

```
Summary of all Effects; design: MRTD
1-ARM, 2-TIME
          df          MS         df          MS
          Effect      Effect     Error       Error      F          p-level
1                 1     15111             8  21424.7   0.70531   0.42539
2                 1    165619             8  19272.2   8.59369   0.01895
12                1   5986.12             8  11313.7    0.5291   0.48772
```

```
Summary of all Effects; PEAK TORQUE
1-ARM, 2-TIME
          df          MS         df          MS
          Effect      Effect     Error       Error      F          p-level
1                 1    65.718             8  16.1388   4.07205   0.07831
2                 1   416.024             8  11.4531   36.3242   0.00031
12                1   1.44801             8  6.34037   0.22838   0.64551
```

```
Summary of all Effects; AVERAGE TORQUE
1-ARM, 2-TIME
          df          MS         df          MS
          Effect      Effect     Error       Error      F          p-level
1                 1   62.3042             8  14.9124   3.92347   0.08324
2                 1   411.213             8  12.2735   35.2346   0.00012
12                1   1.02385             8  5.91237   0.34859   0.71236
```

MVC TRAINED ARM

```
Summary of all Effects;TORQUE
1-GROUP, 2-TIME, 3-INTERVAL
          df      MS      df      MS
          Effect  Effect  Error   Error   F       p-level
1              1  175.8        8  91.98   1.911   0.204
2              1   3142        8    112   28.06   7E-04
3              5   1210       40  9.806   123.4   3E-23
12             1  7E-06        8  48.01   2E-07       1
13             5  11.79       40  4.269   2.762   0.064
23             5  0.408       40  3.249   0.126   0.986
123            5  2.674       40  3.343     0.8   0.556
```

```
Tukey HSD test; TORQUE
Probabilities for Post Hoc Tests
MAIN EFFECT: PREPOST
          {1}    {2}
          42.785 50.41407
 1  {1}        1 175.8
 2  {2}        1  3142
```

```
Tukey HSD test; TORQUE
Probabilities for Post Hoc Tests
MAIN EFFECT: INTERVAL
          {1}    {2}    {3}    {4}    {5}    {6}
          34.811 49.004 49.730 49.205 48.582 48.26500
1   {1}           1E-04  1E-04  1E-04  1E-04  1E-04
2   {2}    1E-04          0.92      1  0.992  0.915
3   {3}    1E-04   0.92          0.98  0.632  0.368
4   {4}    1E-04      1   0.98         0.957  0.797
5   {5}    1E-04  0.992  0.632  0.957         0.998
6   {6}    1E-04  0.915  0.368  0.797  0.998
```

MVC **TRAINED ARM**

Summary of all Effects; AG
1-ARM, 2-TIME, 3-INTERVAL

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.016	8	0.448	0.036	0.854
2	1	0.174	8	0.554	0.314	0.591
3	5	0.178	40	0.029	6.164	3E-04
12	1	0.005	8	0.546	0.01	0.924
13	5	0.023	40	0.018	1.323	0.274
23	5	0.069	40	0.021	3.237	0.015
123	5	0.019	40	0.015	1.29	0.287

Tukey HSD test; AG
Probabilities for Post Hoc Tests
MAIN EFFECT: INTERVAL

	{1}	{2}	{3}	{4}	{5}	{6}
	.70944	.79093	.83898	.83984	.89147	.8991333
1 {1}		0.343	0.028	0.026	8E-04	5E-04
2 {2}	0.343		0.835	0.825	0.146	0.098
3 {3}	0.028	0.835		1	0.778	0.666
4 {4}	0.026	0.825	1		0.79	0.68
5 {5}	8E-04	0.146	0.778	0.79		1
6 {6}	5E-04	0.098	0.666	0.68	1	

Tukey HSD test; AG
Probabilities for Post Hoc Tests
INTERACTION: 2 x 3

	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}
	.67180	.78822	.83687	.85640	0.792	.86075	.74708	.79364	.84110	.82328
1 1 {1}		0.432	0.06	0.021	0.467	0.017	0.917	0.365	0.048	0.114
1 2 {2	0.432		0.997	0.956	1	0.934	0.999	1	0.994	1
1 3 {3	0.06	0.997		1	0.995	1	0.783	0.999	1	1
1 4 {4	0.021	0.956	1		0.944	1	0.527	0.976	1	1
1 5 {5	0.467	1	0.995	0.944		0.918	1	1	0.991	1
1 6 {6	0.017	0.934	1	1	0.918		0.468	0.961	1	1
2 1 {7	0.917	0.999	0.783	0.527	1	0.468		0.998	0.732	0.911
2 2 {8	0.365	1	0.999	0.976	1	0.961	0.998		0.997	1
2 3 {9	0.048	0.994	1	1	0.991	1	0.732	0.997		1
2 4 {1	0.114	1	1	1	1	1	0.911	1	1	
2 5 {1	1E-04	0.005	0.075	0.18	0.005	0.214	5E-04	0.007	0.091	0.038
2 6 {1	3E-04	0.126	0.645	0.872	0.112	0.907	0.016	0.159	0.701	0.461

MVC TRAINED ARM

Summary of all Effects; ANT
1-ARM, 2-TIME, 3-INTERVAL

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.035	8	0.032	1.098	0.325
2	1	0.006	8	0.005	1.233	0.299
3	5	0.024	40	0.003	8.92	9E-06
12	1	0.016	8	0.011	1.452	0.263
13	5	0.005	40	0.002	2.392	0.055
23	5	0.002	40	0.002	1.106	0.372
123	5	0.002	40	0.002	0.86	0.516

Tukey HSD test; ANT
Probabilities for Post Hoc Tests
MAIN EFFECT: INTERVAL

		{1}	{2}	{3}	{4}	{5}	{6}
		.13736	.16087	.16915	.18658	.18670	.2118049
1	{1}		0.394	0.115	0.003	0.003	1E-04
2	{2}	0.394		0.983	0.297	0.293	0.002
3	{3}	0.115	0.983		0.704	0.698	0.013
4	{4}	0.003	0.297	0.704		1	0.318
5	{5}	0.003	0.293	0.698	1		0.323
6	{6}	1E-04	0.002	0.013	0.318	0.323	

Summary of all Effects; ANT/AG
1-GROUP, 2-TIME, 3-INTERVAL

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.071	8	0.073	0.976	0.352
2	1	0.045	8	0.033	1.369	0.276
3	5	0.022	40	0.008	2.731	0.032
12	1	0.076	8	0.138	0.553	0.479
13	5	0.005	40	0.008	0.615	0.689
23	5	0.002	40	0.005	0.482	0.787
123	5	0.007	40	0.004	1.989	0.101

Tukey HSD test; ANT/AG
Probabilities for Post Hoc Tests
MAIN EFFECT: INTERVAL

		{1}	{2}	{3}	{4}	{5}	{6}
		0.197	0.228	0.221	0.228	0.23	0.24
1	{1}		0.958	0.959	0.11	0.541	0.045
2	{2}	0.958		1	0.474	0.954	0.263
3	{3}	0.959	1		0.473	0.953	0.262
4	{4}	0.11	0.474	0.473		0.932	0.999
5	{5}	0.541	0.954	0.953	0.932		0.764
6	{6}	0.045	0.263	0.262	0.999	0.764	

MVC CONTROL ARM

```
Summary of all Effects; PEAK MRTD
1-TIME
        df      MS      df      MS
        Effect  Effect  Error   Error   F       p-level
1            1   1904        9  12730   0.15    0.708

Summary of all Effects;  PEAK TORQUE
1-TIME
        df      MS      df      MS
        Effect  Effect  Error   Error   F       p-level
1            1  43.19        9  8.271   5.221   0.051

Summary of all Effects;  AVERAGE TORQUE
1-TIME
        df      MS      df      MS
        Effect  Effect  Error   Error   F       p-level
1            1  53.36        9  13.36   3.993   0.077
```

MVC CONTROL ARM (TIME INTERVALS)

Summary of all Effects; TORQUE
1-TIME, 2-INTERVAL

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	320.1	9	80.17	3.993	0.077
2	5	722.3	45	11.87	60.83	7E-19
12	5	11.96	45	4.996	2.394	0.052

Tukey HSD test; TORQUE
Probabilities for Post Hoc Tests
MAIN EFFECT: INTERVAL

		{1}	{2}	{3}	{4}	{5}	{6}
		29.17	43.71	44.78	44.33	43.28	42.92400
1	{1}		1E-04	1E-04	1E-04	1E-04	1E-04
2	{2}	1E-04		0.923	0.993	0.999	0.978
3	{3}	1E-04	0.923		0.998	0.74	0.536
4	{4}	1E-04	0.993	0.998		0.927	0.788
5	{5}	1E-04	0.999	0.74	0.927		1
6	{6}	1E-04	0.978	0.536	0.788	1	

MVC CONTROL ARM (TIME INTERVALS)

Summary of all Effects; AG
1-TIME, 2-INTERVAL

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.019	9	0.273	0.069	0.798
2	5	0.068	45	0.01	7.031	6E-05
12	5	0.007	45	0.011	0.614	0.69

Tukey HSD test; AG
Probabilities for Post Hoc Tests
MAIN EFFECT: INTERVAL

		{1}	{2}	{3}	{4}	{5}	{6}
		.6065	.7147	.7479	.7646	.7256	.7568200
1	{1}		0.014	7E-04	2E-04	0.005	4E-04
2	{2}	0.014		0.893	0.602	0.999	0.756
3	{3}	7E-04	0.893		0.994	0.979	1
4	{4}	2E-04	0.602	0.994		0.809	1
5	{5}	0.005	0.999	0.979	0.809		0.916
6	{6}	4E-04	0.756	1	1	0.916	

Summary of all Effects; ANT
1-TIME, 2-INTERVAL

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	5E-04	9	0.003	0.158	0.701
2	5	0.004	45	5E-04	7.328	4E-05
12	5	5E-04	45	3E-04	1.646	0.168

Tukey HSD test; ANT
Probabilities for Post Hoc Tests
MAIN EFFECT: INTERVAL

		{1}	{2}	{3}	{4}	{5}	{6}
		.0871	.1025	.1085	.1185	.1200	.1247895
1	{1}		0.302	0.055	0.001	7E-04	2E-04
2	{2}	0.302		0.96	0.26	0.175	0.041
3	{3}	0.055	0.96		0.748	0.617	0.247
4	{4}	0.001	0.26	0.748		1	0.953
5	{5}	7E-04	0.175	0.617	1		0.987
6	{6}	2E-04	0.041	0.247	0.953	0.987	

Summary of all Effects; ANT/AG
1-TIME, 2-INTERVAL

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	8E-05	9	0.008	0.011	0.92
2	5	0.006	45	0.003	2.157	0.076
12	5	0.001	45	0.002	0.695	0.63

1RM TRAINED ARM

Summary of all Effects; WT
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	8.2101	8	1.7054	4.8141	0.0595
2	1	34.708	8	1.666	20.833	0.0018
12	1	22.804	8	2.1712	10.503	0.0119

Tukey HSD test;WT
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

	{1} 15.4133	{2} 15.7853	{3} 14.7766	{4} 18.33222
11 {1}		0.9479	0.7972	0.0129
12 {2}	0.9479		0.5052	0.0263
21 {3}	0.7972	0.5052		0.0041
2 2{4}	0.0129	0.0263	0.0041	

Summary of all Effects; AG
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.0657	8	0.1371	0.4793	0.5083
2	1	0.3104	8	0.1132	2.741	0.0543
12	1	0.0888	8	0.0303	2.9334	0.1251

Summary of all Effects; ANT
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.0065	8	0.0023	2.7997	0.1328
2	1	9E-05	8	0.0003	0.3186	0.5879
12	1	0.0013	8	0.0016	0.786	0.4012

Summary of all Effects; ANT/AG
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	0.0004	8	0.0099	0.0394	0.8476
2	1	0.0184	8	0.0033	5.5436	0.0464
12	1	0.0012	8	0.0035	0.3424	0.5746

1RM CONTROL ARM

```
Summary of all Effects; WT
1-TIME
        df      MS      df      MS
        Effect  Effect  Error   Error   F       p-level
1            1  0.221        9  1.369   0.161   0.698

Summary of all Effects; 1AG EMG
1-TIME
        df      MS      df      MS
        Effect  Effect  Error   Error   F       p-level
1            1   0.05        9  0.024   2.109    0.18

Summary of all Effects;  ANT EMG
1-TIME
        df      MS      df      MS
        Effect  Effect  Error   Error   F       p-level
1            1  5E-04        9  2E-04   2.935   0.121

Summary of all Effects;  ANT/AG EMG
1-TIME
        df      MS      df      MS
        Effect  Effect  Error   Error   F       p-level
1            1  1E-03        9  0.002   0.402   0.542
```

FIBRE AREAS TRAINED ARM

```
Summary of all Effects; design: FIBRE 1=RESISTANCE 2=BALLISITIC
1-ARM, 2-FIBRES, 3-TIME
        df      MS      df      MS
        Effect  Effect  Error   Error    F        p-level
1            1  9E+06       16  5E+06   1.8647    0.191
2            2  9E+07       32  560667  158.06    3E-17
3            1  5E+06       16  604998   8.962   0.0086
12           2  119874      32  560667  0.2138   0.8086
13           1  2E+06       16  604998  4.0433   0.0615
23           2  176357      32   82654  2.1337   0.1349
123          2  487995      32   82654  5.9041   0.0066

Tukey HSD test; variableFIBRE
Probabilities for Post Hoc Tests
MAIN EFFECT: FIBRES
        {1}     {2}     {3}
        3424.5  6287.5  5968.342
1 {1}           0.0001  0.0001
2 {2}   0.0001           0.183
3 {3}   0.0001   0.183

Tukey HSD test;FIBRE
Probabilities for Post Hoc Tests
MAIN EFFECT: TIME
        {1}     {2}
        5002.7  5450.879
1  {1}          0.0088
2  {2}  0.0088
```

FIBRE AREAS **TRAINED ARM**

Tukey HSD test; FIBRE
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2 x 3

	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}	{11}	{12}
	3503.8	3828.7	6184.7	7086.8	5714.6	6734.9	3054.1	3311.4	5897.0	5981.6	5662.1	5761
1 1 1 {1}		0.4358	0.0001	0.0001	0.0001	0.0001	0.0793	0.9509	0.0001	0.0001	0.0001	0.0001
1 1 2 {2}	0.4358		0.0001	0.0001	0.0001	0.0001	0.0002	0.0244	0.0001	0.0001	0.0001	0.0001
1 2 1 {3}	0.0001	0.0001		0.0001	0.0562	0.0132	0.0001	0.0001	0.6115	0.9304	0.0221	0.1208
1 2 2 {4}	0.0001	0.0001	0.0001		0.0001	0.3227	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
1 3 1 {5}	0.0001	0.0001	0.0562	0.0001		0.0001	0.0001	0.0001	0.9657	0.7084	1	1
1 3 2 {6}	0.0001	0.0001	0.0132	0.3227	0.0001		0.0001	0.0001	0.0002	0.0003	0.0001	0.0001
2 1 1 {7}	0.0793	0.0002	0.0001	0.0001	0.0001	0.0001		0.7515	0.0001	0.0001	0.0001	0.0001
2 1 2 {8}	0.9509	0.0244	0.0001	0.0001	0.0001	0.0001	0.7515		0.0001	0.0001	0.0001	0.0001
2 2 1 {9}	0.0001	0.0001	0.6115	0.0001	0.9657	0.0002	0.0001	0.0001		1	0.84	0.9967
2 2 2 {10}	0.0001	0.0001	0.9304	0.0001	0.7084	0.0003	0.0001	0.0001	1		0.4605	0.8875
2 3 1 {11}	0.0001	0.0001	0.0221	0.0001	1	0.0001	0.0001	0.0001	0.84	0.4605		0.9998
2 3 2 {12}	0.0001	0.0001	0.1208	0.0001	1	0.0001	0.0001	0.0001	0.9967	0.8875	0.9998	

1 = RESISTANCE 2 = BALLISTIC

FIBRES AREAS CONTROL ARM

Summary of all Effects; FIBRE AREAS CONTROL
1-FIBRE, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	25888402	16	589330.5	43.9285	3.17E-07
2	1	64666.09	8	269544.9	0.239908	0.637421
12	2	14452.35	16	16051.88	0.900353	0.426052

Tukey HSD test; FIBRES AREAS CONTROL
Probabilities for Post Hoc Tests
MAIN EFFECT: FIBRE

	{1}	{2}	{3}
	3293.757	5499.208	5213.013
1 {1}		0.000168	0.000169
2 {2}	0.000168		0.517042
3 {3}	0.000169	0.517042	