ADAPTATIONS TO BALLISTIC AND HEAVY RESISTANCE TRAINING

PERFORMANCE AND NEUROMUSCULAR ADAPTATIONS TO HEAVY RESISTANCE AND BALLISTIC TRAINING

By

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ABSTRACT

The purpose of this investigation was to compare performance and neuromuscular adaptations following ballistic and heavy resistance training. Twenty male university students were divided into a training (n=10) or control group (n=10). Each subject in the training group, by random assignment, trained the elbow extensors of one arm with heavy resistance (HR) [(5 sets of the maximal weight that could be lifted for 5-7 repetitions (reps.)]; the other with ballistic (BL) actions (5 sets of 6 reps. at 10% of their isometric MVC). Training was done 3 times per week for 17 weeks. Following training, both training HR and BL regimens produced significant ($p \leq 0.05$), but not significantly different increases in ballistic performance peak torque (2.5 vs. 2.7 N·m, peak velocity (1.0 vs. 1.3 $\text{rad}\cdot\text{s}^{-1}$), and peak power (32.8 vs. 48.4 W). Similarly, elbow extension movement time decreased to the same extent (-12.5 vs. -6.3 ms; $p \leq 0.05$). In contrast, HR training produced significantly greater increases in maximal weight lifting (1 RM) (15.8 vs. -0.1 N·m; $p \leq 0.001$) and isometric (MVC) strength (8.1 vs. 0.8 N·m; $p \leq 0.01$). Electromyography (EMG) recordings of the agonist (AG) triceps brachii indicated significant ($p \leq 0.05$) increases in average EMG (AEMG) during 1 RM, MVC, and ballistic tests (collapsed across training conditions). The only difference between training regimens was the greater 1 RM AEMG after HR training. Ballistic training resulted in significantly ($p \leq 0.05$) greater antagonist ballistic/MVC, and antagonist coactivation (ballistic/MVC) EMG ratios compared to HR training. Evoked isometric twitch torque and torque-time integral increased only after HR training. Fiber (needle biopsies of triceps) area increases were also significantly ($p \leq 0.001$) larger in the HR than the BL arm after training in type I (28.0% vs. -4.7%), type IIa (43.0% vs. 8.3%), and type IIb (41.4% vs. 3.0%) fibers. Dual photon x-ray absorptiometry regional arm analysis revealed that only the HR arm significantly ($p \leq 0.05$) increased in lean mass following training. Heavy resistance training resulted in a significant ($p \leq 0.05$) decrease in the percentage of type IIb fibers with a corresponding increase in IIa; whereas ballistic training did not result in any fiber type conversion. These data suggest that although neuromuscular adaptations may differ, either form of training can increase ballistic performance, but only HR training is effective in increasing muscle size and maximal force during 1 RM and MVC single joint actions.

Heavy Resistance, Ballistic, Torque, Velocity, Power, Electromyography, Evoked Contractile Properties, Fiber Type, and Fiber Area

This thesis is dedicated to my parents, Robert and Karla Bauer,

for their encouragement, love, support, and always believing
in me, no matter what distance or extreme I went too.

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Two final thing to say,
it's much better to burn out,
than fade away.
and
the World Cup belongs to the USA!!

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PREFACE

This thesis is presented in two parts. The first chapter is a literature review of the characteristics and adaptations of heavy resistance and ballistic training. The second chapter presents the thesis research of the performance and neuromuscular adaptations to heavy resistance and ballistic training.

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CHAPTER I

REVIEW OF LITERATURE

INTRODUCTION

It has been suggested that muscular power is a basic requirement or major factor in most athletic activities (Adams et al., 1992; Stone & O'Bryant, 1987). Unfortunately for athletes wanting to improve their ability, performance of the high velocity power movements (jumping, sprinting, throwing) may be largely determined by genetic endowment, as speed is said to be mainly an innate quality and not influenced as much by training as is peak force, perhaps partly because training-induced increases in speed/power are so difficult to achieve (Wilmore & Costill, 1994). Nevertheless, coaches and athletes have devised and practiced various training techniques with the goal of increasing speed and power performance. Controversy has arisen over the best training techniques and programs. (Coyle & Feiring, 1980; Moffroid & Whipple, 1970; Narici et al., 1989; Newton et al., 1995). The main controversy appears to be whether actual fast or "ballistic" training actions are most effective, or whether the same results can be achieved, with less injury risk, by relatively slow actions against high resistance (Poliquin, 1990; Sale & MacDougall, 1981; Schmidtbleicher & Buehrle, 1987; Schmidtbleicher & Haralambie, 1981). The specificity in training between these two training programs is believed to predict the outcome of the results (↑ maximal force or ↑ rate of force production) (Alen et al., 1984)

This review will compare ballistic actions with slow movements associated with conventional heavy resistance training, in terms of mechanical properties and neural control. Neuromuscular adaptations to the two types of training actions will also be reviewed, with an emphasis on implications for speed and power performance.

1.1 MECHANICAL CHARACTERISTICS OF HEAVY RESISTANCE AND BALLISTIC ACTIONS

Two of the most common modes of training to improve these mechanical characteristics (force, velocity, acceleration, rate of force development, and power) are heavy resistance and ballistic training. Heavy resistance training involves slow movements with loads that approach maximal force capacity, while ballistic training consists of fast actions with a high rate of force development against low resistance. Ballistic movements by their definition may be thought of as actions that release high speed projectiles, but generally are not confined to the projection of an object when used in physiological context. In this text ballistic actions will refer to high velocity actions that may or may not project an object, but an attempt is made to accelerate through to the end of the movement . The two types of training actions can be put into the context of the concentric load-velocity-power relationship as depicted in the top panel of Figure 1. The values in Figure 1 are from one subject's data while performing an elbow extension with different loads. Similar curves have been produced with overhand throwing of weighted implements (Zatsiorsky & Matveev, 1964, referenced in Zatsiorsky, 1995). In order for a ballistic action to take place the resistance acting against the movement must be low enough to allow high velocity and acceleration. Because the resistance is low and the velocity is high, the peak force that can be generated is also low compared to those attained by typical heavy resistance movements (Fig. 1, top panel). It is hypothesized that as the speed of sarcomere shortening increases, less time is available for the myosin head to bind to an actin binding site, decreasing the chance of formation of a cross-bridge (Huxley, 1979; Huxley & Simmons, 1973). Therefore, since the number of cross-bridges is proportional to the force generating capacity of the muscle, less external force can be produced (Edman, 1992) during ballistic actions.

1.1.1 FORCE

The term one repetition maximum (1 RM) is commonly used to refer to the peak force attained in heavy resistance weight training (a single maximal lift). Conventional resistance training may involve resistance loads as low as 60% of the 1 RM (Sale & MacDougall, 1981) with maximal gains in peak force being produced with loads above 66% of the 1 RM (McDongh & Davies, 1984). In contrast, ballistic training usually uses loads in the range of 0% to 30% of the 1 RM, while the subject attempts to perform the training (concentric) actions as fast as possible (Bauer et al., 1995; Wilson et al., 1993). A comparison of the force-time characteristics of actions with loads equivalent to ~85% 1 RM and 10% isometric MVC (maximal voluntary contraction) is shown in Figure 2. The striking difference in peak force attained and the duration of force development is evident.

A similar comparison could be made of low and high velocity concentric actions done on an isovelocity or "isokinetic" training device. On these devices, various pre-set velocities limit the velocity of contraction attained. This is in contrast to weight lifting devices, in which various preset loads limit the force generated. Interestingly, a lower velocity on weight lifting devices does not always produce a higher force, as attempts to perform heavy resistance repetitions with an emphasis on a higher velocity have been shown to produce higher forces than the same load performed slowly (Palmieri, 1987). However, besides the velocity and load used, peak force can also vary with the task and type of muscle action (concentric, eccentric, isometric), and should be described using all the parameters involved in the action (Knuttgen & Kraemer, 1987).

1.1.2 RATE OF FORCE DEVELOPMENT (RFD)

A high rate of force development is a quality often attributed to ballistic actions. As the external load that is being moved is reduced, 1 RM peak force becomes less influential, while rate of force development (RFD) becomes the predominant factor related to the development of high velocity actions (Bührle, 1985; Bührle & Schmidtbleicher, 1981; Werschoshanskij, 1972; all referenced in Schmidtbleicher, 1992). A high RFD is said to be very important in sports where the resistance must be overcome quickly such as in boxing, shot put, and javelin (Schmidtbleicher, 1992). Müller (1987), found that loads of 25-100% of MVC had equal MRFD values (cited in Schmidtbleicher, 1992). Accordingly, an 85% 1 RM load with a MRFD of 175 $N \cdot m \cdot s^{-1}$ is a lot smaller than that produced by a 10% MVC ballistic load with a MRFD of 500 $N \cdot m \cdot s^{-1}$ (Fig. 2). However, it might be that MRFD is not related to the speed of movement or the external load as much as the effort to produce a force quickly. One study found that as long as the intent is to move quickly, even an isometric action can cause high rates of force development (Behm & Sale, 1993). This is demonstrated by the fast rate of force development during a "explosive" 85% 1 RM (Fig. 3) with a similar MRFD (653 $N \cdot m \cdot s^{-1}$) as the ballistic action. In spite of this result, most training practices use slow continuous movement with minimal emphasis on RFD, possibly fearing potential risk of injury. Risk of injury is believed to be caused by ballistic actions, especially those with a counter-movement, or when resistance is added (Brady et al., 1982; Brown et al., 1990). The exception is olympic lifting, in which certain phases of the lifts require large inertial forces to be generated in a short period of time. The highest lifting forces in the clean and snatch lift last approximately 800 milliseconds (ms) while the jerk lift is much shorter at 200 ms (Garhammer & Takano, 1992). However, just like other forms of heavy resistance training, analysis of vertical bar velocity, peak applied vertical force and/or peak power outputs have shown that increasing the load decreases all these measures (Garhammer and Takano, 1992). So although both modes of training can attain a high RFD, generally only does ballistic training always intend to produce maximal RFD. During most heavy resistance training exercises the emphasis is on lifting the desired load relatively slowly.

1.1.3 VELOCITY & ACCELERATION

Ballistic actions are considered to be those movements performed with the highest velocity and acceleration (Zehr & Sale, 1994). Since velocity and acceleration are inversely related to the load imposed and thus the force produced, peak accelerations and velocities are much higher in lightly resisted ballistic actions compared to heavy resistance movements. Figure 2 shows the differences in velocity and acceleration between conventional heavy resistance and ballistic training actions. The initial rise in acceleration with the attempted high velocity ("explosive") action using the heavy resistance load (Fig. 3) is still quite small and short-lived compared to the ballistic action in (Fig. 2). Both ballistic and heavy resistance training exercises can require a deceleration at the end of the movement that can be intuitive to the movement or because of safety concerns. It has been shown that as the weight is reduced from a 1 RM to 81% of a 1 RM the deceleration increases 24-52% in the bench press exercise (Elliot et al., 1989). This may be due to the higher velocities attained with the lower resistance of 81% of the 1 RM, resulting in a larger deceleration by movement end. Also of importance could be the amount of movement time that is devoted to the deceleration of these heavy loads, which presumably is much smaller in ballistic actions. If the loads can be released, there may be minimal or no deceleration during ballistic actions.

Movement time is related to velocity (time=distance/velocity) when the movement distances are equal, and ballistic movements are thought to occur in most cases with movement times of less than 300 ms (Newton & Kraemer, 1994), while heavy resistance training movements can vary in length depending primarily on the load and intent. Even a fast isometric ramp action with a time to peak of 500 ms (Desmedt, 1981) is still relatively slow in comparison to a dynamic ballistic action. The same conclusion can be made during fast dynamic actions shown in the bottom panel of Figure 1 with the subject completing the movement in .138 s at a 0% of MVC load whereas it took 1.54 s at 90% of MVC. Generally however, heavy resistance lifts last for 2-5 seconds, with an emphasis on slow "controlled" movement. The terms ballistic and "explosive" are used interchangeably when describing quick movements with high acceleration, but explosive movements, although assumed to continue to the end of movement, may just be intended for part of the movement (Newton & Kraemer, 1994).

Motor learning researchers have examined acceleration profiles to determine whether or not performers are making use of response-produced feedback to modify movements. If corrections that meet certain predetermined amplitude and temporal criteria can be identified in specific acceleration profiles, feedback-based connections can be inferred (i.e. heavy resistance action). If the criteria are not met, then the action would be considered to occur without feedback; i.e. a ballistic action (Chua & Elliott, 1993; Elliot et al., 1995). With the lack of acceleration profiles for all movements and ease of classification using other parameters, the limb actions with the shortest movement times, highest velocities and accelerations are generally considered ballistic, while the rest could be termed *ramp* movements. Heavy resistance exercise would be considered ramp movements, but as Stone (1993) pointed out, it could be considered an explosive action, if the intent is to develop a high RFD or velocity even though the actual movement is restricted to moving slow because of the load used.

1.1.4 POWER

High power outputs are often thought of as being associated with a short contraction time and a high velocity (Perrine, 1986). However, peak power has been shown to be attained at approximately 30% of maximal muscle force and peak velocity (Faulkner et al., 1986) and 30-42.5% of 1 RM loaded jump squats (Kaneko et al., 1983; Moritani et al., 1987) cited in Moritani (1992), and standing press (Mastropaolo, 1992). Olympic lifts can produce some of the highest power outputs attainable in athletic performance (5500 W, clean and jerk; 5400 W, snatch, [Stone, 1993]). However, their velocity, acceleration, and movement times are not what would be considered ballistic unless only part of the movement is considered, exclusively. The second pull in these olympic lifts, where the highest power is developed, displays a duration range from 100-200 ms, but the whole movement lasts longer (800+ ms), even in elite lifters (Garhammer, 1993). The use of external loads has not always resulted in increase in power, since two legged jumps with added load have shown decreased mechanical power output (Davies & Young, 1984). In the current literature it appears that ballistic movements, or at least movements which would not be considered heavy resistance actions, produce the highest power (Fig. 1). The exception appears to be olympic lifts which are generally thought of as being heavy resistance training exercises.

1.2 MOTOR UNIT & MUSCLE ACTIVATION IN HEAVY RESISTANCE AND BALLISTIC ACTIONS

In terms of central nervous system (CNS) control, heavy resistance movements would be classified as *ramp* movements that occur with continuous peripheral feedback (closed loop), while *ballistic* movements are preprogrammed (open loop) actions that are completed before sensory feedback can make modifications to movement (Desmedt &

Godaux, 1979). Ramp and ballistic motor control are thought to involve different higher brain structures. The basal ganglia function in generating slow ramp actions, while the cerebellar cortex is involved in the pre-programming and initiation of ballistic actions; they have been referred to as "function generators" (Kornhuber, 1971, cited in Desmedt & Godaux, 1978). Research in monkeys (while the basal ganglia is involved in control of slow ramp actions) performing ballistic, rapidly alternating and tracking movements also support the cerebellum as performing a specialized role in ballistic action (Delong & Strick, 1974; Ivry et al., 1988; Yamamoto & Mano, 1980). Hamada (1981) has suggested that the motor cortex specifies the muscle and level of intensity of activation. If this is the case, then the "function generators" must act to control the discharge that regulates the force and rate of force development (Zehr & Sale, 1994) Recently, specific discharge patterns generated by the basal ganglia have been suggested to be evident during different movement strategies and velocities (Brotchie et al., 1991a; 1991b).

As will become evident in section 1.5 (Training Adaptations), various training modes affect the muscles and muscle fiber types differently, which suggests that the motor units containing these fibers may be recruited and/or receive different patterns of activation (Gardiner, 1991). The following section will examine the differences in how the two actions activate motor units and the muscles involved in these actions. For additional reviews on neural characteristics and adaptations to heavy resistance and ballistic actions, see Behm (1995), Moritani (1993), Sale (1986,1988), and Zehr and Sale (1994).

1.2.1 MOTOR UNIT RECRUITMENT

The functional unit of the peripheral nervous system and muscle is the *motor unit (MU)*. The MU consists of an alpha motor neuron and all the muscle fibers it innervates. There are three primary motor unit types that have been identified by both histochemistry glycogen depletion techniques: fast glycolytic (FG), fast oxidative glycolytic (FOG), and slow oxidative (SO) (Edstrom & Kugelberg, 1968); and electrophysiology (evoked motor unit contractile characteristics): fast-fatigable (FF), fast fatigue-resistant (FR), and slow (S) (Burke, 1981). Both classification schemes, along with the corresponding fiber type based on ATPase histochemistry, are summarized in Table 1. Fast motor units produce the greatest twitch tension (tension from a single action potential) (Burke et al., 1971), due to greater fiber numbers and size (Bodine et al., 1987) per motor unit. These motor units and fibers as described by their name, also have the shortest contraction times, but fatigue rapidly in relation to the slow motor units (Burke, 1981).

The force a muscle generates is graded by the recruitment of the number of motor units recruited and by the firing rates of recruited motor units. When force is increased in a gradual manner such as during ramp contractions (from zero to MVC), motor units are typically recruited from slow to fast (Milner-Brown et al., 1973). This recruitment order is in accordance with the *size principle of recruitment.* This principle was first proposed by Henneman et al. in 1965, wherein sequential recruitment of motor units depended on the size of the motor neuron (soma and dendrite tree) . Small neurons with higher input resistance are recruited (begin to discharge) before large neurons, with low input resistance, if excitation to motor neurons is distributed homogeneously (Henneman & Mendell, 1981; Kernell, 1983). These low threshold (slow) MUs also display slower axonal conduction velocities (Borg et al., 1978)

1.2.2 SELECTIVE MOTOR UNIT ACTIVATION

Although it is generally accepted that a systematic order of recruitment (S→ FR→ FF) is followed, selective activation of fast MUs in humans (Grimby & Hannerz, 1977; Hannerz, 1974) has been reported during rapid actions. In these two studies this condition only occurs in humans when the muscle is in a very relaxed state and then activated with the intent to produce a maximal and short duration action. The benefit of such action may be observed during fast alternating movements which could be impaired by contracting S MUs (Edstrom & Grimby, 1986), not allowing the fastest response. However, others have not observed such a reversal of recruitment order in ballistic actions, and believe that the size principle holds for these movements (Desmedt & Godaux, 1977;1978;1979).

Caution has been recommended in the interpretation of the apparent reversals of the recruitment order of fast and slow motor units. A fast motor neuron discharging just after a slow one, will conduct its nerve impulse more rapidly to the muscle fiber, and may be the first to elicit muscle action potentials, giving the impression of a reversal in recruitment order (Desmedt, 1981). But this would not explain exclusive recruitment of the fast motor units.

Also shown to change the recruitment order, is the type of muscle action performed. Rapid (Nardone et al., 1989) and slow (Howell et al., 1995) lengthening actions have displayed preferential activation of FT MUs. Fast MUs were recruited, while slow MUs were being derecruited (Nardone et al., 1989, Howell et al., 1995). The activation of these fast units has been proposed to provide better control of the movement during lengthening, (Nardone et al., 1989), and/or provide a faster response time to alterations in the movement during the eccentric action (Howell et al., 1995). Movement pattern may also determine selective activation of some MUs depending on the task that is required; such as rotational actions around the elbow joint. Ter Harr Romeny et al. (1984) observed MUs in the lateral head of the biceps brachii to be selectively activated during elbow flexion, while forearm supination selectively recruited MU in the medial head. The recruitment threshold may also be affected by the joint angle (van Zuylen et al., 1988) and type of muscle action (Tax et al., 1989). These apparent "violations" of the size principle warrant further research using larger muscle groups, and under varying muscle action types and ranges of motion. However, investigations are often limited because of the difficulty in recording the same motor unit from one condition to the next, due to movement of the intramuscular electrode.

1.2.3 MOTOR UNIT FIRING RATES

Increasing the stimulation frequency of the muscle fibers is the second way of varying not only force output, but also the rate at which force is developed. During brief maximal ballistic actions, motor units may fire at frequencies up to 120 Hz (Desmedt & Godaux, 1977) for 50-100 ms prior to the onset of movement, and may end before force can develop (Desmedt & Godaux, 1979). These high firing rates are much higher than required for maximum force production (50 Hz) (Grimby et al., 1981), and above those achieved in slow ramp actions (Tanji and Kato, 1973b). The characteristic high RFD observed during ballistic actions is related to MU discharge rate. Typically, MU discharge spikes having a constant interspike interval (distance between successive spikes) (Desmedt & Godaux, 1978; Freund, 1983), but during ballistic actions the high frequency discharges may produced MU discharge inter-spike intervals that are reduced for the initial two discharges compared to subsequent inter-spike intervals. Although peak force may not be influenced by these high firing rate characteristics, the rate of force development could be increased (Zehr & Sale, 1994). But if the movement is brief enough, such that peak force is reached quickly, it may be possible for these high firing rates to contribute to an enhanced peak force. In fact, it is suggested that the firing frequency is the main regulator of power during ballistic actions (Edstrom & Grimby, 1986)

1.2.4 MUSCLE ACTIVATION PATTERNS

The activation pattern of agonist and antagonistic muscles differs between ballistic and heavy resistance actions. The pattern of activation can sometimes distinguish the two movements.

A technique called electromyography (EMG) allows the recording and quantification of muscle fiber electrical activity giving a representation of the muscle's activation pattern. The agonist activation pattern during heavy resistance (ramp) actions display a continuous burst from the onset of movement until the end (Fig. 4). With increasing muscle force the amount of agonist integrated EMG (IEMG) increases. The increase has been shown to be linear (Bigland & Lippold, 1954), non-linear (Komi & Buskirk, 1972), and to demonstrate no fixed relationship between concentric and eccentric actions (Ghori et al., 1995). It is not clear if the discrepancy between studies is due to experimental procedures, recording difficulties, anatomical, and/or physiological differences (Bigland-Ritchie, 1981). Coactivation of the antagonist is also present during heavy resistance actions. Snow et al. 1993 tested isokinetic torque at knee joint angular velocities of 30°/s and 90°/s through 65° of motion, both concentrically and eccentrically. Co-contraction was significantly higher in the antagonist hamstrings at the highest velocities and joint angles. A mean coactivation of 32% of the agonist was observed in low velocity isokinetic knee joint actions (30-90°/s) (Snow et al., 1993). Isometric MVC of the knee extensors have also produced biceps femoris activation of 22% of its maximal value (Carolan & Cafarelli, 1992). Although coactivation would seem detrimental to producing high agonist torques and velocities, it may function to decelerate the limb (Marsden, et al., 1983), prevent injury, and maintain joint integrity with increasing velocities (Osternig et al., 1986). Besides angular joint velocity (McGrain, 1980; Osternig et al., 1984; Osternig et al., 1986: Snow et al., 1993), joint angle, and contraction type (eccentric or concentric) (Snow et al., 1993) can also affect the amount of co-contraction.

Ballistic actions may demonstrate a triphasic pattern of agonist (Ag1), antagonist (Ant2), then agonist activation (Ag2) (Angel, 1974, 1975: Cooke & Brown, 1990). The initial agonist onset is followed by a cessation of the agonist until the end of movement (Stetson 1905; Stetson & McDill, 1923; referenced in Desmedt & Godaux, 1978). Movements of 400 ms or less (ballistic) produce the most frequent occurrence of the triphasic pattern (Brown & Gilleard, 1991). Ballistic isometric actions also display the triphasic pattern in the elbow flexors and extensors (Gordon and Ghez, 1984). However, not all ballistic actions produce a triphasic pattern, but a continuous activation pattern like that of heavy resistance actions are also common (Fig. 4). But unlike the gradual buildup seen during heavy resistance actions, muscle activity increases abruptly in ballistic actions (Fig. 4). In the ballistic actions that produce the triphasic pattern of activation, the suggested purpose has been that the Ag1 burst produces the acceleration of movement, while the Ant2 burst acts to decelerate movement, and the Ag2 burst halts the negative deceleration produced by the Ant2 burst (Cooke & Brown, 1990). The three phases of the triphasic burst pattern overlap to varying degrees resulting in the co-contraction observed in ballistic movements (Cooke & Brown, 1990; Marsden et al., 1983). Coactivation occurs primarily in complex movements, during simple rapid movements (Basmajian, 1978), and while learning new high velocity motor tasks (Engelhorn, 1983; McGrain, 1980). Isokinetic testing of high velocity (400°/s) knee extensions, however, has produced significantly more coactivation than at a slow velocity (100°/s) (Osternig et al., 1986). Little else is known about the effects of and reasons for antagonist coactivation during ballistic or heavy resistance actions.

The selective activation of muscles of a predominant fiber type during certain high velocity movements would seem beneficial and warranted to maximize the use of the faster contraction time of these muscles. And in fact, the selective activation of a fast muscle and inhibition of slow muscle has been observed in the cat ankle extensors Smith et al., (1980) during rapid paw shakes, but not during normal locomotion. As the authors pointed out, in cats, ground contact time is 120-150 ms, the swing phase lasts 300-350 ms during running, and in jumping the force development lasts 150-250 ms, comparable to the twitch contraction time for slow muscles (Smith et al., 1980). This allows both motor unit types time to contribute to force development, so the need for selective recruitment in "normal" activities may be unnecessary. An example of a greater contribution by a predominantly fast muscle over a slower muscle in humans was seen as cycling speed increased under a constant load. The medial gastrocnemius (MG) activation increased with increasing speed, while the soleus (SOL) activation decreased slightly. Also observed was the early onset of the SOL activity, during slow pedaling (60 rpm) followed by the MG, but simultaneous activation during high speeds (170 rpm), demonstrating the possibility of not only changes in the amount, but of the timing of activation between slow and fast muscle during high versus low velocity movements (Duchateau et al., 1986). Rapid voluntary lengthening (eccentric action) of human triceps surae has also produced a selective activation, with the relaxation of the soleus (slow muscle) and increased activation of the lateral gastrocnemius (fast muscle) (Nardone & Schieppati, 1988). Although this research shows the possibility of selective muscle activation with differing fiber types, its direct application to human athletes with most muscles having a heterogeneous fiber type distribution is currently limited. What these studies may lead to is further developments in the possibility of selective activation of different muscles, motor unit types, and motor unit regions within the same muscle during specific types of actions.

1.3 TRAINING METHODOLOGY

Many studies have focused on the optimal number of repetitions, sets, resistance (load or intensity), exercise, and frequency for heavy resistance training. A review on manipulations of these variables has been done by Fleck & Kraemer (1987) and Stone and O'Bryant, (1987) and is beyond the scope of this review. The purpose of heavy resistance training as previously mentioned is to increase high force production, while ballistic training is performed to increase speed of movement and mimic the athletic exercises to improve the motor task performance. Typical resistance training programs range in repetitions from 1-5 for olympic weightlifters to 6-15 for bodybuilders. Observation of training practices and the extreme hypertrophy of bodybuilders suggest a higher number of repetitions is required to attain high levels of muscle hypertrophy. However, olympic lifters possess a great deal of muscle mass in their legs and back, and although repetitions are generally low, most exercises (snatch, clean & jerk, and squats) are performed every workout and require the use of both muscle groups (Garhammer & Takano, 1992). In the early development of these athletes, repetitions may be higher such that a large percentage of their mass could also have been attained prior to the reduction in repetitions (Garhammer & Takano, 1992).

Training for ballistic events requiring high velocity power often incorporate performance of the sporting activity or similar drills with the addition of resistance through the use of weighted implements (heavier balls and sleds pulled in sprinting) (Judge, 1992; Robins, 1990), air resistance (sprint parachute) and inclination (hill sprinting) (Dintiman & Ward, 1988). Over-speed training is also employed where an attempt is made to reach velocities higher than attained during the event. This form of training uses pulley systems during sprinting, lighter implements, down hill sprinting, and elastic material to assist the work done by the athlete (Dintiman & Ward, 1988; Phillips, 1987). Resistance, number of sets, and repetitions vary depending on the activity, but are usually low enough for the athlete to still attain a high velocity of movement and maintain proper technique with minimal fatigue. Since a variety of training modes may be employed for ballistic training depending on the athlete's sporting activity, a general number of reps and sets is difficult to ascertain. Both types of training can consist of single and/or multi-joint exercises, the use of body weight, free weights, and/or machines.

A training system in which changes in exercises, volume (repetitions and sets) and intensity (% 1 RM) are adjusted for different periods in the athletes yearly and monthly is called "periodization". This type of training is used in both heavy resistance (Stone et al., 1981, 1982) and ballistic "plyometric" training (Bompa, 1993). For further information see Stone & O'Bryant (1987) and Bompa (1990, 1993).

There is the possibility of injury with the high loads and velocities produced during heavy resistance and ballistic training respectively. Some believe that ballistic training, especially with counter-movements, or when resistance is added, results in high impact loads that may cause injury (Brady et al., 1982; Brown et al., 1990b). However, others have stated that this form of training provides the best results to improve high velocity power (Adams et al., 1992; Young and Bilby, 1993) or is of no greater risk to injury than other sport activities (Stone, 1993). Another argument against ballistic training, is that even though a subject believes they have given maximal effort, they appear to have difficulty in predicting the quality of their effort (better than previous effort). As well, in most ballistic activities (throwing, jumping, punching etc..) feedback is not always available, whereas during most heavy resistance actions, the load lifted provides direct feedback. To examine the rationale behind why ballistic and heavy resistance training are so frequently used by power athletes, the training adaptations of both will now be reviewed.

1.4 TRAINING ADAPTATIONS

The following review will focus on the effects of ballistic and heavy resistance training, both separately and in comparison. Isometric and low velocity (velocities <90° s^{-1}) isokinetic training will be included as heavy resistance training. High velocity isokinetics and repetitive movements like sprint cycling and running will be included under ballistic training due to the lack of available research directly comparing dynamic ballistic and heavy resistance training programs.

1.4.1 MOTOR PERFORMANCE

Anecdotal evidence for the use of heavy resistance training to improve vertical jump performance has been observed in olympic weightlifters who exhibit a high level of performance in the vertical jump (Stone, 1990, cited in Garhammer & Gregor, 1992). The high levels of maximal strength associated with superior jumping ability, and take-off velocity during a vertical jump have also raised the interest in heavy resistance training as a way to improve motor performance (Baker et al., 1993). In fact, most studies employing heavy resistance training have produced significant increases in vertical jump performance (Adams et al., 1992; Baker et al., 1994; Bauer et al., 1990; Chui, 1950; Fry et al., 1991; Perrine & Edgerton, 1975; Stone et al., 1981; Wilson et al., 1993; Young & Bilby, 1993), with only a few investigations not observing significant changes (Komi et al., 1982; Van Oteghen, 1973). The effects of heavy resistance training on other motor performance activities are less clear, with some significant changes observed in throwing velocity (Potteiger et al., 1992; Wooden et al., 1992), but mostly non-significant results predominate in throwing velocity (Bloomfield et al., 1990; Straub, 1968), sprint running (Fry et al., 1991; Wilson et al., 1993), and cycling performance (Wilson et al., 1993).

Training studies of explosive jumping, sprinting, and throwing over-and under-loaded weighted balls have also reported significant increases in vertical jump height

(Adams et al., 1992; Wilson et al., 1993), sprint speed (Mero et al., 1992) and throwing velocity (Brose & Hanson, 1967; DeRenne et al., 1990; Van Muijen et al., 1991), respectively. Jump training has not significantly increased sprint running (Fry et al., 1991; Wilson et al., 1993) or cycling speed (Wilson et al., 1993). The same is true for sprint training on a non-specific motor performance task such as 60 second jumping power (Callister et al., 1988). These results suggests that ballistic motor performance tasks show the greatest improvement following training that is highly specific; i.e., jump training for jump performance.

Of the few studies that have directly compared heavy resistance and plyometric (ballistic) jumping exercise, plyometric training increased vertical jump to a greater extent (Adams et al., 1992; Berger, 1963; Komi et al., 1982; Wilson et al., 1993). Interestingly, the combination of the two training modes has been found to be superior to either performed separately (Adams et al., 1992). It may be that the benefits of both types of training have a summation effect: specificity of the task for ballistic training, and increased strength from heavy resistance training. A type of training believed to maximize power and still allow specificity of training; namely, jump squats with loads equal to 30% of 1 RM, improved vertical jump (counter-move) performance significantly more than heavy resistance training (Berger, 1963; Wilson et al., 1993). It should be noted that in both of these studies the peak power training was not significantly more effective than plyometric (ballistic) training. The current available research indicates that although heavy resistance training can increase high velocity performance activities, plyometric, light load, or peak power training is more effective when used singly, but the combination of training modalities may provide superior performance. Further investigation into the combination of these training practices is warranted before further conclusions can be drawn.

1.4.2 KINETIC AND KINEMATIC PERFORMANCE

1.4.2.1 FORCE

Increases in isometric peak force are frequently demonstrated following heavy resistance training (Häkkinen et al., 1985a ; Keen et al., 1994; Schmidtbleicher & Bührle, 1987; Wilson et al., 1993). Even more investigation on the improvement of 1 RM testing following heavy resistance training has been conducted and summarized by Kraemer et al. (1988). One RM or isometric strength is not always correlated with high velocity performance measures, posing the question of how these tests accurately predict improvements in high velocity movements. Most investigations of high velocity movement specificity have been conducted using isokinetic training devices (e.g. Biodex) to control the velocity of movement. Velocities most often trained range from low (≤ 100°/s) to high (≥201°/s to 300 °/s) (Bell & Wenger, 1992) Although in most studies results show that the closer the training velocity is to the testing velocity the greater the percent improvement in peak torque (Behm & Sale, 1993; Caiozzo et al., 1981; Coyle et al., 1981; Ewing, et al., 1990; Kanehisa & Miyashita, 1983), there are still conflicting results since significant improvement for high velocity training at and below the training speed has been shown (Adeyanju et al., 1983; Behm & Sale, 1993; Costill et al., 1979; Lesmes et al., 1978). Intermediate velocities of 180°/s, showed similar significant effects only at and below the training velocity (Costill et al., 1979; Lesmes et al., 1978), and for both faster and slower (Adeyanju et al., 1983; Coyle et al., 1981; Kanehisa & Miyashita, 1983) testing velocities. The problem with this type of evaluation is that the testing velocities are below maximal limb velocity (De Koning et al., 1985; Nygaard et al., 1983), which could potentially limit the effects of ballistic training, if these high velocities are needed to show maximal gains in peak force. Recently, two studies demonstrated that dynamic ballistic elbow extension training with loads ranging from 0%-20% of the isometric MVC can increase dynamic ballistic peak torque at a load equal to 10% of the MVC by 8.3% after 5 weeks (Bauer et al., 1994) and 10.9% after 10 weeks of training 2 times per week (Bauer et al., 1995). From the evidence thus far, it appears that ballistic training can increase ballistic peak torque.

Studies that have directly compared ballistic and heavy resistance training show similar increases in low velocity strength (Newton & McEvoy, 1994; Palmieri, 1987; Voigt & Klausen, 1990). In contrast, Häkkinen and colleagues in 1985 investigating the effects of two training programs (one that included explosive jump training, the other heavy resistance training over 24 weeks), did not come to this conclusion. In the first study the leg muscles were trained using heavy resistance concentric loads from 70-100% of 1 RM and eccentric actions with loads from 100-120% (Häkkinen et al., 1985a), while the second study had subjects perform explosive jumping exercise without and with extra load (10-60% 1 RM), drop jumps, and strengthening exercises using weight of 60-80% of the 1 RM 3 times per week (Häkkinen et al., 1985b). Isometric MVC increased to a greater extent (26.8%) following heavy resistance compared to a more modest (10.8%) increase after the combined explosive (ballistic) jump and strength training, both increases being significant (Häkkinen et al., 1985a,b). This was not unexpected as the heavy resistance group trained with resistance equal to or higher (eccentric actions) than their MVC.

Conclusive evidence shows that high resistance, low velocity training increases low velocity strength, and appears to have minimal effect on high velocity isokinetic peak force, whereas ballistic training improves high, and, to a lesser extent, low velocity peak force. The present studies, however, do not demonstrate how dynamic high velocity peak force might change after training when directly comparing ballistic and heavy resistance training, as the comparison studies only tested 1 RM, isokinetic, or isometric peak force.

1.5.2.2 RATE OF FORCE DEVELOPMENT

In many athletic events (e.g. high jump, sprinting) the ability to generate maximum force quickly has been said to be as important as maximal force generating capacity (Schmidtbleicher, 1992). In certain activities RFD may even be of greater importance, as ski jumpers were found to produce greater RFDs than controls even though isometric MVCs were similar (Viitasalo & Komi, 1978). Although ballistic movements cannot attain as high a force output as heavy resistance actions, they do produce a high RFD, and therefore by their nature may invoke adaptations to improve RFD. Therefore, athletes who lack maximal force should use heavy resistance training, and those who need to improve RFD should perform plyometric exercises (Wilson & Murphy, 1995).

Significant increases in maximal RFD have been observed after heavy resistance (Young & Bilby, 1993) and ballistic training (Bauer et al., 1994; 1995; Behm & Sale, 1993; Häkkinen, 1985b), while other studies have not witnessed these significant increases following either heavy resistance (Häkkinen et al., 1985a; Häkkinen & Keskinen, 1989) or ballistic training (Wilson et al., 1993). Although maximal RFD did not change in two studies following heavy resistance training, portions of the isometric force-time curve have shown increased RFD (Häkkinen et al., 1985a). The discrepancy between these studies could be due to the previous training status of the subjects (Komi & Häkkinen, 1988; Wilson et al., 1993), as it has been suggested that after a base level of force generating capacity has been achieved, changes in RFD may become extremely difficult (Komi & Häkkinen, 1988). Also, there may be limited correlation between dynamic training actions and isometric testing, as only two studies (Bauer et al., 1994; 1995) used dynamic RFD testing. The study by Young & Bilby (1993), employing attempted fast and slow heavy resistance training, showed that although both training protocols can increase isometric RFD, the group that attempted to move the weight quickly had a much larger mean increase (68.7%) following training when compared with the group that trained slowly (23.5%) (Young & Bilby, 1993). This suggests that heavy resistance training can be effective in improving RFD, but the intent to move ballistically, or at least as fast as possible, may provide a greater benefit. Support for this hypothesis can be found in a study by Behm and Sale (1993), who demonstrated in a within subjects design that both ballistic isometric and isokinetic (300 °/s) dorsiflexion training increase RFD. The authors attributed the increase in both limbs to the intended attempt to move ballistically, but not dependent on actual limb movement, and on the high RFD achieved by both actions (Behm & Sale, 1993).

In summary, it appears that both training programs can improve isometric RFD, but the intent to move ballistically used in most ballistic exercises may provide a greater stimulus. How meaningful improvements in isometric RFD are to athletic performance remains in question, as the relationship between the two has been shown to be quite low in sprint performance (Mero et al., 1981), and medicine ball throw (Wilson & Murphy, 1995).

1.4.2.3 VELOCITY & ACCELERATION

The effects of either heavy resistance or ballistic training programs on maximum velocity and acceleration of the human limb has not received much investigation. It is generally thought by coaches and athletes that to improve limb velocity and acceleration training must include ballistic activities, since such training has been shown to increase limb velocity (Bauer et al., 1995; Duchateau & Hainaut, 1984; Kaneko et al., 1983) and acceleration (Bauer et al., 1994; 1995). However, studies including dynamic (Voigt & Klausen, 1990) and isometric (Duchateau & Hainaut, 1984; Kaneko et al., 1983) heavy resistance training have also improved limb velocity. Duchateau & Hainaut 1984 conducted a study where two training groups performed either isometric MVCs or ballistic 30-40% of maximum force contractions with the adductor pollicis for 3 months. The results showed that MVC training increased the velocity of movement at high loads and ballistic training increased velocity at low loads, but only ballistic training increased the theoretical maximal velocity of shortening (Vmax) derived from Hill's equation. Both training programs seem capable of increasing limb velocity, but the increase may be more favorable for the testing load that is closest to the training load as has been found with peak force tested by isokinetic devices.

1.4.2.4 POWER

Greater gains in peak mechanical power have been reported following training with loads of approximately 30% of maximum at high velocities (ballistic) (Kaneko et al., 1983; Kaneko, et al., 1974; Moritani et al., 1987, cited in Moritani, 1992). Heavy resistance isometric training has also been shown to increase peak power (Duchateau & Hainaut, 1984). In fact, in this study the group training with peak power loads (30-40% of max.) did not significantly increase maximum power as much as the isometric MVC training group (19% vs. 51% ↑ power) (Duchateau & Hainaut, 1984). In a study by Kaneko et al. 1983, although training with a load equal to 30% of MVC was superior for increasing peak power compared to all other training loads (0%, 30%, 60% & 100% of MVC), the group that trained with the 100% load did significantly improve and was superior to the other two loads (Kaneko et al., 1983). Isokinetic training at high and low velocities has also been shown to increase peak power, and since the velocity is controlled, any increase in peak torque will function to increase power, so will not be discussed in this review. The results of changes in power following isokinetic training are reviewed elsewhere in detail (Morrissey et al., 1995).

It has been suggested that to improve maximum power, loads of 50-75% of the 1 RM should be used in olympic lifting exercises; however, no research has yet investigated the superiority of one load over another during olympic lifting (Poprawski, 1988). Nevertheless, recommendations for using 80% of 1 RM for olympic lifts have also been suggested (Garhammer, 1989). It may be that peak power in these athletic activities can be attained above 30% of 1 RM. What needs to be determined is what load these athletes can lift for a 1 RM with no emphasis on velocity of movement during the portion of the lift that produces the most power, to determine what percentage of their slow velocity 1 RM they are developing in these high power outputs. These results suggest that both training protocols can improve power with training loads closest to the tested load (specificity of training), but ballistic loads close to the movement's peak power generating capacity (~ 30% of MVC) may provide superior results in increasing peak power.

1.4.3 NEURAL ADAPTATIONS

Training-induced increases in strength, power, and speed (performance) are likely the result of adaptations in the nervous system (neural) and muscles. The next section will review evidence for neural adaptations, and where possible, comparisons between heavy resistance and ballistic training will be made.

1.4.3.1 AGONIST ACTIVATION

An obvious neural adaptation is increased activation of agonist muscles in maximal voluntary contractions. Increased activation would reflect the recruitment of more motor units and/or increased firing frequency of these units. The most common method to measure increased activation has been integrated electromyography (IEMG).

It is generally accepted that an increase in EMG represents the ability of the subject to more fully activate the prime movers involved during a MVC following training (Sale, 1988). Significant increases in agonist EMG have been reported following isometric (Komi et al., 1978; Weir et al., 1994), isokinetic (Narici et al., 1989), and weight training (Häkkinen & Komi, 1983; Häkkinen & Komi, 1986; Häkkinen et al., 1985a; Moritani & DeVries, 1979; Keen et al., 1994) heavy resistance studies. In contrast, other studies using similar training protocols have not produced a significant change in EMG (Baker et al., 1994; Cannon & Cafarelli, 1987; Garfinkel & Cafarelli, 1992; Thorstensson et al., 1976; Weir et al., 1995). Barbell squat exercise training for 8 weeks resulted in a significantly large increase in the 1 RM squat test, a smaller but significant increase in isometric leg press force, but no increase in force or EMG in the isometric knee extension (Thorstensson et al., 1976). The recording of EMG in the leg extension MVC and not the trained squat movement may have resulted in the lack of change in EMG. This lack of change in EMG may have resulted from EMG being recorded in the leg extension MVC and not the trained squat movement (Sale, 1988).

Possible explanations for the lack of increase in EMG in the previous studies include: 1) different modes and action types (isometric vs. isotonic) of testing compared to those used during training (Baker et al., 1994; Thorstensson et al., 1976); 2) testing of muscles that are not solely responsible for force production (Weir et al., 1994;1995), and 3) a decrease in opposing force production by antagonist activation (Weir et al., 1994; 1995). Other possibilities include training program duration and intensity and whether the subject was required to maintain balance during testing (Enoka, 1988). Whether or not fiber area increased following training may also influence the amount of EMG, as the action potential size from a muscle fiber, may be proportional to the mass of the fiber. If the electrode pickup area remains the same pre vs. post training a change in fiber density would need to occur to result in changes to EMG. Currently there is no evidence of such changes, as non-contractile tissue which makes up only 13% of total muscle volume remains proportionate after increases in fiber size due to heavy resistance training (MacDougall, 1984). Also, in a study of motor unit fiber density, the authors believed it would be unlikely that muscle hypertrophy would cause a high fiber density, as the subject with the smallest fiber size had the highest fiber density (Larsson & Tesch, 1986).

The only study to examine agonist EMG following ballistic ("explosive" jump) training did not show a significant increase (Häkkinen & Komi 1986), but earlier work by these authors did demonstrate an increase when training was combined with heavy resistance training (Häkkinen, et al., 1985b). Although there was no significant difference between combined training and heavy resistance training alone, a specific training effect was observed at the onset of activation, and EMG increased 38% more than peak EMG following the ballistic/weight training (Häkkinen, et al., 1985b), while weight training alone (Häkkinen, et al., 1985a) produced only a small (3%) increase in the later portion of the activation (Sale, 1988). This adaptation may have been due to the high frequency burst pattern of motor units seen only during ballistic actions at the onset of the agonist burst, resulting from the higher firing rates inherent to ballistic actions (Sale, 1988; 1992). An important neural adaptation to ballistic training is increased maximal motor unit firing rates; however, there are technical limitations to monitoring firing rates before and after training.

Plyometric drop-jump training, a form of ballistic training, may produce neural adaptations due to the high stretch loads on ground contact. When dropping from a height of 110 cm to the floor, untrained subjects displayed a decrease in agonist activation (inhibition) during the eccentric phase of landing, while experienced jumpers produced an increased amount of agonist activity (facilitation) (Schmidtbleicher & Gollhofer, 1982 cited in Sale, 1992). The decrease in agonist activation by untrained subjects has been attributed to the sudden stretch force stimulating a reflex inhibition response by the Golgi tendon organ to reduce the tension at the tendomuscular unit, acting as a protective mechanism to the high peak forces (Gollhofer et al., 1987). In comparing the effects of this high stretch load in experienced jumpers versus untrained individuals, experienced jumpers demonstrate superior jumping ability from certain drop heights (Komi, 1984). The differences observed may be inherent to the stretch overloads encountered during trained athletes' performance activities (Sale, 1988; 1992).

Increased agonist activation has also been indicated as increased reflex potentiation. Potentiation has been observed in heavy resistance training in longitudinal (Milner-Brown et al., 1975; Sale et al., 1983a), as well as cross-sectional studies of weightlifters (Milner-Brown et al., 1975; Sale et al., 1983b) and sprinters (Upton & Radford, 1975). Karate-trained (ballistic) athletes also displayed increased reflex response manifesting in a larger increase in the long-latency myotatic pathways preceding movement (Mortimer & Webster, 1983). The possible effect of such potentiation is that any signal from the higher brain centers will be amplified on reaching the brain stem and spinal cord (Enoka, 1988).

Another adaptation of agonist activity may be an increase in synchronization of the involved motor units. A cross-sectional study comparing weight training and control subjects, and a heavy resistance longitudinal training study, revealed greater motor unit synchronization with training (Milner-Brown et al., 1975). How this increased synchronization may affect force production, is not clear. During submaximal firing rates, force production is superior with asynchronous motor unit discharge, and equal in force output to synchronous motor unit activation when firing frequencies are similar to those in maximal efforts (Lind & Petrofsky, 1978; Rack & Westbury, 1969). There is no evidence as to the effects of ballistic training on synchronization; however, it has been suggested that although maximal force may not be affected, a increase in RFD following ballistic training may be observed (Sale, 1988, Schmidtbleicher, 1992). This could provide a beneficial neural adaptation since ballistic performance is thought to be determined more by rate of force development than by peak force (Schmidtbleicher, 1992). When voluntary isometric MVCs were compared to evoked tetanic activation with frequencies beyond what can occur voluntarily (200 Hz), RFD was higher in the voluntary MVC (Miller et al., 1981). It appears then; that an increased synchronization has little effect on enhancing performance. The effect of synchronization on larger muscle groups and during dynamic movements seen in most athletic performances is unknown.

The interpolated twitch method (% motor unit activation - MUA) (Belanger & McComas, 1981) could also be used to monitor agonist activation, but has been done so only in a heavy resistance study involving prepubescent boys, with inconclusive results (Ramsay et al., 1990). This technique is limited in that the testing is done under isometric conditions only, and studies have shown full voluntary muscle activation in untrained subjects in some muscle groups, but not in others (Belanger & McComas, 1981). For more information on this technique and how increases in MUA might be affected by training see Sale (1987; 1988).

It has been postulated that by training across different ranges of motion, velocities (Jones et al., 1989) and loads (Sale, 1987) subjects may be able to better activate the controlling muscles, but to date, no direct comparison between heavy resistance and ballistic training has produced increased agonist activation following ballistic training or monitored EMG while performing these actions. Heavy resistance training has also been inconclusive in showing changes in agonist activation following training. Current knowledge of agonist activation following ballistic and heavy resistance training is limited by analysis techniques and lack of research.

1.4.3.2 COACTIVATION OF ANTAGONIST

Very few studies have investigated the effects of coordination in improving performance through increased synergistic and decreased antagonistic activation accompanying improved agonist activation. Barratta et al. (1988) found that athletes whose sports required frequent jumping had less coactivation during isokinetic knee extension than control subjects. Following testing two jump athletes performed a hamstring curl exercise for two weeks, which increased their antagonist coactivation to similar values as the control subjects (Barratta et al., 1988). The opposite effect was found in untrained subjects, with coactivation of the antagonist (biceps femoris) muscle decreasing after 8 weeks of isometric leg extension training. Most of the reduction (20%) was observed after the 1st week (Carolan & Cafarelli, 1992). The decrease in coactivity was accompanied by a 32.8% increase in force, with no change in agonist EMG suggesting a causative effect (↓ antagonist EMG = ↑ MVC extension force). However, the majority of the increase in force came after the decrease in coactivation such that only 10.2% of the increase in force was explained by a adaptations in EMG coactivation (Carolan & Cafarelli, 1992).

Although not a direct comparison between ballistic and heavy resistance trained athletes, isokinetic testing at 100°/s and 400°/s has demonstrated that sprinters can produce a significant 4 fold (58/14%) increase in coactivation hamstring (antagonist) compared to distance runners during leg extensions, suggesting that frequent high-intensity short duration muscular efforts may have produced a residual hamstring tension that manifested itself in increased antagonist coactivation (Osternig et al., 1986).

However, a later study revealed that endurance athletes possessed greater coactivation during a slow knee extension designed to stretch the hamstrings (Osternig et al., 1990). Although this may suggest higher coactivation closer to the athletes training speed, these tests are not specific to the actions performed by the athletes in competition. How heavy resistance and ballistic action training might affect antagonist coactivation following long-term training is not known, and warrants further investigation.

As evident in the present section, very little is known about how the nervous system adapts to control agonist-antagonist muscle activation following training. It would seem reasonable that, to improve performance, a decrease in coactivation following both types of training is required, either through increased agonist or decreased antagonist activity, or a combination of the two. As difficult and complex as it is to study single and multi-joint movements under different joint angles, velocities, and loads, it is even more difficult to analyze and understand how training affects these actions.

1.4.4 SKELETAL MUSCLE ADAPTATIONS

The most frequently studied area, after functional performance, is skeletal muscle adaptations following heavy resistance and ballistic training. The next sections will discuss the adaptations in muscle following ballistic and heavy resistance training. Due to the lack of data on ballistic training, adaptations to sprint training will be included where applicable.

1.4.4.1 CONTRACTILE PROPERTIES

Electrically evoked twitch and tetanus contractile properties assess muscle function uninfluenced by voluntary control. Measurements are usually made under isometric conditions. As illustrated in Figures 5 & 6, twitch contractions can be analyzed in terms of peak force or torque, time to peak force, and half -relaxation time. Twitch and tetanic contractions are evoked by percutaneous nerve stimulation. Tetanic stimulation can be painful; consequently, twitch contractions are more commonly studied. Contraction time (CT) is used interchangeably in the literature with time to peak torque (TPT).

1.4.4.1.1 ADAPTATIONS TO HEAVY RESISTANCE TRAINING

Evoked in vivo contractile property data of human muscles following training are presented in Table 2. The peak twitch torque appears to increase or not change following heavy resistance training, and in ballistic actions, only concentric exercises cause an increase. Two of the heavy resistance studies (isometric) were of relatively short duration (5-6 wks), and may not have been long enough for training adaptations to occur (Davies & Young, 1983; McDonagh et al., 1983). Evidence that training may have been of insufficient duration comes from cross-sectional studies of strength-trained athletes (bodybuilders and/or powerlifters) who have shown greater peak twitch torque than untrained controls (Sale et al., 1983) and endurance athletes (Alway et al., 1988). Increases in peak twitch torque after 12-24 wks of heavy resistance training in prepubescent boys (Ramsay et al., 1990), young female and male adults (O'Hagan, unpublished Masters thesis') and elderly men (Brown et al., 1990; Rice et al., 1993) also support that a longer duration of training might be necessary to bring about adaptations in peak twitch torque. Other evidence for a slow time course was given by McDonagh & Davies (1984), who stated that voluntary strength increases faster than evoked force (1% vs. 0.2% per day). A longer period of training may be necessary to increase peak torque significantly. Another possibility for the discrepancy in changes in peak torque could be related to the type of muscle action (isometric vs. isotonic), and/or muscle group trained (see Table 2).

It might be thought that because heavy resistance training is generally performed in a slow controlled manner, the motor unit (peripheral nerve and muscle) may adapt to become slower in regard to its contractile property temporal measures, but in fact, heavy resistance isometric training has demonstrated that the CT either remains constant or decreases (Table 2.). However, two studies of elderly male elbow flexors (Brown et al., 1990) and extensors (Rice et al., 1993) have demonstrated a significant increase in the time-related properties (HRT, TPT respectively) following training. In contrast, these parameters were not affected by weight training (Ramsay et al., 1990), consistent with that of young adults (O'Hagan, unpublished Masters thesis). Aging has been shown to increase the temporal contractile properties in humans (Belanger & McComas, 1989; Vandervoort & Hayes, 1989). Strength training may counteract the increased stiffness of connective tissue encountered during aging, while the younger adult's musculo-tendinous compliance (series elastic component) may not be affected (Rice, et al., 1993). Alway et al. (1988) have also suggested that if a muscle is more elastic, it will take longer for the series elastic component to be taken up, extending the time to peak twitch torque.

1.4.4.1.2 ADAPTATION TO BALLISTIC TRAINING

It could be speculated that ballistic training may cause a decrease in evoked time-related contractile properties that would be advantageous to improving high velocity events, and with the limited data on ballistic performance, this possibility may exist. Behm & Sale (1993) did in fact show a decrease in CT and HRT after their subjects trained either isokinetically or isometrically with the intent to move "explosively"; in contrast, Bauer et al. (1995) did not observe changes in either of these measures following ballistic elbow extensions. The different results may have been due to differences in the type of training action performed and/or muscle group involved. The only study to directly compare ballistic and heavy resistance training produced a nonspecific effect in PT, but did demonstrate training specificity in the thumb that trained ballistically with a increase in RFD, and a decrease in CT and HRT (Duchateau & Hainaut, 1984). Animal studies using "high" speed running, support the observation of a decrease in contraction time (Staudte et al., 1973; Troup et al., 1986). The rate at which force can be developed (RFD) has been found to increase in some ballistic studies (Bauer et al., 1995; Duchateau & Hainaut, 1984), but not in others (Behm & Sale, 1993). A reasonable explanation for the conflicting results between studies, could be that more than one factor affects evoked contractile properties (see below), or the lack of sufficiently precise measures of the intrinsic muscle properties.

1.4.4.1.3 POSSIBLE MECHANISMS FOR ADAPTATIONS IN CONTRACTILE PROPERTIES

Peak twitch torque is influenced by the quantity of contractile protein, and adaptations in excitation-contraction coupling and series-elastic component (Keen et al., 1994). Evoked time measures are likely influenced by adaptations in excitation-contraction coupling (Alway et al., 1989) and the series-elastic component (Rice et al., 1993). Fiber type may also affect contraction time and RFD, as Vmax and RFD of single fibers are different in different fiber types. In single fibers, RFD is thought to be related to the rate at which myosin binds to actin (Brenner & Eisenberg, 1986), while Vmax is believed to be influenced primarily by the rate of disassociation between the myofilaments (Fitts et al., 1991). Rate of force development in fast fibers has been reported to be 7 times faster than slow fibers (Metzger & Moss, 1990). Maximum shortening velocity of type II, IIa and IIb fibers have been reported as being approximately 5-6 (Fitts et al., 1989), 3 and 10 (Larsson & Moss, 1993) times faster, respectively, than type I fibers.

With this in mind, it would be expected that a fiber which expressed a higher percentage of fast myosin, or a muscle with a higher percentage of fast fibers, would possess a higher RFD and shorter CT. However, it is doubtful that fiber type alterations from training would cause a shift towards a faster muscle and that would result in increased movement speed (see section 1.4.4.6). Selective type II fiber hypertrophy has also been dismissed as the only cause of changes in twitch contraction time since no change was observed in type II/I fiber area ratios in the soleus muscle with a ~30% decrease in contraction time (Alway et al., 1989). It is possible that changes in contractile properties may be independent of the percent change in fiber type (Alway et al., 1988). For a more in-depth review into possible mechanisms, see Alway et al. (1988; 1990b) and Rice et al. (1993)

In summary, ballistic and heavy resistance training appear to increase or have no effect on twitch peak torque. Maximum rate of force development follows a similar pattern. Contraction time does not increase with heavy resistance training, except possibly after many years and extreme hypertrophy as observed in some bodybuilders. Contraction time may only decrease in certain muscles groups, as seen in the case of the triceps surae in heavy resistance training. Half relaxation is not affected by resistance training. The minimal ballistic data in humans is similar to that in animals, and suggests that high velocity training may decrease or have no effect on contractile property measures. A specific adaptation from ballistic training that could be utilized in repetitive bidirectional movements would be a decrease in contraction time and half relaxation time. This adaptation would allow force to build up and dissipate quickly in one muscle group (hamstrings) so as not to oppose the utilization of force in the opposite muscle group (quadriceps). Because of technical difficulty (full muscle activation, transmission of force of the muscle to torque sensor, etc..) and the many factors that may be involved in producing the evoked response in human in vivo conditions, changes observed in contractile properties should be interpreted with caution.

1.4.5.2 MUSCLE SIZE

Anatomical cross-sectional area (ACSA) is the measure of the largest CSA along the length of the muscle. Force output is highly correlated with ACSA, identifying the latter as a primary factor in the amount of force that can be developed (Ikai & Fukunaga, 1970; Maughan et al., 1983; Maughan and Nimmo, 1984). Although the quantity of muscle does not always determine its force generating capacity in voluntary contractions, 50% of the variation in force development between people can be accounted for by CSA (Rutherford, 1986, cited in Jones et al., 1989). Significant increases in muscle size using limb girth (Cureton et al., 1988; Häkkinen et al., 1985), ultrasound (Ikai and Fukunaga, 1970; Young & Bilby 1993), computer tomography (CT) scan (Cureton et al., 1988; Luthi et al., 1986), magnetic resonance imaging (MRI) (Housh et al., 1992; Keen et al., 1994; Narici, et al., 1989; Trueth et al., 1994), and dual photon absorptiometry (DPX) (Calder et al., 1994; Trueth et al., 1994) measurement techniques have been reported after heavy resistance training. In comparing heavy resistance studies (Cureton et al., 1988; Frontera et al., 1988; Ikai and Fukunaga, 1970; MacDougall et al., 1977) a 9-23% increase in muscle ACSA in response to studies ≤6 months in duration has been reported (Timson, 1990). In examining athletes that have been using heavy resistance training for years a much greater increase in muscle hypertrophy can be observed (MacDougall et al., 1984).

Sprint training, with the exception of one study (Thorstensson et al., 1975) has not produced muscle hypertrophy (Allemeier et al., 1994; Esbjornsson, et al., 1993; Jansson et al., 1990). Isokinetic studies using angular speeds of ≥300°/s have shown no increase in muscle size (Coyle et al., 1981), while velocities below 300°/s have produced muscle hypertrophy (Housh et al., 1992; Narici, et al., 1989). The decreased torque and duration of muscle actions at higher limb velocities may explain the lack of change at high velocities (Sale, 1987).

1.4.4.3 MUSCLE FIBER SIZE

Increased muscle CSA is highly correlated with increased muscle fiber areas (McDonagh and Davies, 1984; Schantz et al., 1983). Muscle CSA is primarily determined by the number and size of fibers, with minimal contribution from connective tissue (MacDougall, 1992). Although some studies have demonstrated similar hypertrophy of all fiber types following heavy resistance training (Frontera et al., 1988; Tesch and Larsson, 1982), most have reported greater (Staron et al., 1989; Tesch et al., 1987) or selective (Alway, et al., 1989; Coyle et al., 1981; Häkkinen et al., 1985a; Houston et al., 1983; MacDougall et al., 1979; 1980; Tesch et al., 1985; Thorstensson et al., 1976) hypertrophy of type II fibers . Selective hypertrophy is considered to occur when only type II fibers increase significantly and/or a type II/I area ratio change is observed following training Some studies have not shown an increase in fiber area, possibly due to the use of isokinetic concentric actions (Costill et al., 1979), concurrent endurance training in young adults (Sale et al., 1990), or short training periods (Costill et al., 1979; Staron et al., 1994). The reason for the selective hypertrophy following training may be the relative increased use of the type II fibers during training compared to the normal amount of recruitment during daily activity (MacDougall, 1992).

Quick movements might place more demands on type II fibers to elicit preferential hypertrophy of these fibers (Edström and Grimby, 1986). A cross-sectional study of sprinters gives some support to this line of reasoning (Table 3). But most sprint athletes also train with weights. In contrast to heavy resistance longitudinal studies, no significant increase in fiber area has been reported following sprint cycling training (Thorstensson et al., 1975; Jacobs et al., 1987; Allemeier et al., 1994). Isokinetic training with either low (60°/s) or fast (240- 300°/s) speeds has produced a selective increase in type II fibers after high velocity training in only one study (Coyle et al., 1981), while another has shown no increases after either training mode (Ewing et al., 1990). A study presented in abstract form directly compared ballistic (10% load of 1 RM) and heavy resistance (90% of 1 RM) single joint elbow flexor training and reported no significant difference in the amount of muscle or fiber hypertrophy between the two groups or fiber types (Dahl et al., 1992). Although load was set at 10% 1 RM, the actual force generated in ballistic actions may be greater when acceleration is taken into account. A ballistic load of 10% MVC, when compared to a heavy resistance load of 85% 1 RM, is the equivalent of 11.8% of the resistance load (Fig. 2). But, when the peak torques (23.6 vs. 56.8 N.m) generated by each action are compared, the ballistic action produces a torque equivalent to 41.5% of the heavy resistance action. So, even though heavy resistance loads may be much larger, the actual force difference between the two types of training is not as great.

A comparison of cross-sectional studies of Olympic weightlifters, sprinters, bodybuilders, powerlifters, other athletes and untrained individuals is presented in Table 3. The results from cross-sectional studies are not consistent, but do point to some selective hypertrophy of type II fibers, while others do not reveal any larger fiber area compared to untrained subjects. The discrepancy in the results could be attributed to methodological error, small sample size, and/or muscle group investigated. The fact that a larger muscle mass was seen in all the studies but not always a larger fiber area has yet to be explained, but could be the result of higher fiber numbers or larger interstitial space through training or heredity. Both will be discussed in the following sections. Also, the measurement error for fiber area is likely greater than for whole muscle CSA; therefore, there may be insufficient statistical power (too small sample size) for the fiber data. To summarize, fiber area increases after heavy resistance training but usually not after ballistic training; however, if the volume of training is high and ballistic loads are large enough to develop high force, ballistic training may also increase fiber area, but to a lesser extent.

1.4.4.4 MUSCLE FIBER NUMBER

Another possible mechanism for increasing muscle size is through the proliferation of new muscle fibers (hyperplasia). Although preliminary research with cats using indirect counting methods showed increases in fiber number (Gonyea, 1980) later studies using direct counting (all fibers within the muscle) methods in rats (Gollnick et al., 1981), chickens (Gollnick et al., 1981) and mice (Timson et al., 1985) showed no increase in fiber number. Recently, animal research has shown increases in fiber number in cats following weight lifting (Gonyea et al., 1986) and in a stretched wing model in Japanese quails (Alway, 1993; Alway et al., 1990a). The type of stimulus and animals used in the above studies may account for the differences observed in hyperplasia.

Indirect measures in human cross-sectional studies, based on fiber size (MacDougall et al., 1982; Tesch & Larsson, 1982) and estimation of motor unit fiber density (Tesch and Larsson, 1986), have shown some evidence of greater fiber number in the much larger muscles of bodybuilders compared to controls. In contrast, MacDougall et al. (1984) using muscle CSA (CT scan) and fiber area measurement, estimated that bodybuilders with a minimum of 6 years of training and a biceps area 56% larger than untrained controls did not possess increased fiber numbers. Although most of the elite bodybuilders did have greater muscle size and number than the intermediate group, it was attributed to heredity and not training (MacDougall et al., 1984). To date no longitudinal study has examined the effects of ballistic training on fiber number.

1.4.4.5 MUSCLE PENNATION

With increases in muscle size it has been theorized that muscle fiber pennation angles might increase (Gollnick, 1981). By increasing pennation angles muscle can put hypertrophied fibers on the limited space of the aponeurotic tendon (Gans & Bock, 1965); thus, increasing pennation angle has been thought to be a fiber-packing strategy (Burkholder et al., 1994). In fact, almost all the skeletal muscles in humans are more or less pennate in nature (Feneis, 1946, cited in Gans & Bock, 1965).

With an increase in pennation angle there is a reduction in net force acting along the line of the tendon. But because the muscle can increase in physiological cross-sectional area (PSCA) by filling up with thicker fibers, the net effect can be to increase muscle force, possibly up to a pennation angle of 45 degrees (Alexander & Vernon, 1975). In humans it is proposed that this is unlikely because muscles at resting length display small pennation angles (<10°)(Roy & Edgerton, 1992), but large and variable changes in pennation angles have been observed during normal limb movement (Otten, 1988); thus, muscle pennation angles would significantly affect muscle force - joint movement interaction.

A recent study using male bodybuilders demonstrated a 100%, 77%, and 63% increase in muscle (triceps long and medial head) pennation angles, thickness, and limb girth respectively compared to untrained individuals (Kawakami et al., 1993). In this study, pennation angles of over 50 degrees were observed in highly trained bodybuilders. Another study by these authors was the first to demonstrate increased (16.5° to 21.3°, 29%) fascicle (pennation) angle after 16 weeks of resistance training (Kawakami et al., 1995). It appears that after long training periods and considerable hypertrophy, there are changes in muscle pennation angles. Although no reduction in torque was seen at high isokinetic velocities, like those observed in bodybuilders and weightlifters (Tesch &

Larsson, 1982), specific tension has been shown to decrease with hypertrophy (Kawakami et al., 1995; Maughan et al., 1984). So then, the larger PSCA observed over many months and years of heavy resistance training, may result in increased pennation angles and absolute strength increases, but the force generating capacity of the muscle may be compromised compared to that of untrained muscles (Kawakami et al., 1995)

Although it could be theorized that a large muscle pennation angle may decrease muscle contraction speed (Roy and Edgerton, 1992), recent evidence on rat gastrocnemius muscles has shown an increased speed of muscle shortening with increased pennation angles (Zuurbier & Huijing, 1992). Although the speed of muscle fiber shortening decreases with increased muscle pennation compared to normal resting lengths, aponeurosis velocity of shortening increases providing a net gain in muscle shortening speed (Zuurbier & Huijing, 1992).

Further research is necessary to determine a range of pennation angles above "normal" untrained muscles and how they affect specific and absolute strength. If muscle hypertrophy could occur to a large enough extent to increase muscle pennation, therefore increasing muscle speed and absolute strength, a larger muscle may compensate for the shift to a slower contracting fiber type (see section 1.4.4.6.2) allowing athletes to better develop power. However, it is doubtful that pennation could increase enough to allow pennation derived muscle speed to make up for the reduction in faster contracting fiber. Also, in some athletic activities (vertical jumping, sprinting) that are best performed by athletes that have a high force to muscle mass ratio, there may be a point where further increases in muscle size become counter-productive, regardless of increases in absolute strength.

To the author's knowledge, no study has dealt with ballistic training and pennation angle, and since large increases in hypertrophy are generally not observed with such training, it may be assumed that high velocity training would not greatly affect muscle pennation angles. This occurrence could be seen as a benefit of ballistic training, as there would be less of the reduction in fiber shortening speed that seems to occur when training increases muscle size. Continued research is needed to determine what effect increases in human muscle size; and pennation angles have on velocity of shortening before a conclusion can be made. For further information beyond the scope of this review on the effects of muscle pennation, see Roy and Edgerton (1992).

1.4.4.6 MUSCLE FIBER TYPE COMPOSITION

1.4.4.6.1 CLASSIFICATION

Although there is some controversy as to which classification scheme should be used when attempting to identify fiber type conversions, most of the literature regarding adaptations to ballistic and heavy resistance training uses myofibrillar actomyosin ATPase (mATPase) histochemistry. Recently, the use of gel electrophoresis to identify myosin isoforms has become more common in human training studies. As mentioned previously (section 6.4) Vmax has been shown to correlate with myofibrillar ATPase (enzyme responsible for splitting phosphate from ATP) activity in both whole muscle (Bárány, 1967) and single muscle fibers (Edman et al., 1988). Staron and Johnson (1993) explain that with the discovery that myosin with different ATPase activities could be found in different fiber types (Bárány et a., 1965), and that the heavy chain portion of myosin (MHC) contains the site of ATP hydrolysis (Wagner & Ginger, 1981), a connection between speed of shortening and the muscle fiber content of MHC could be made. This has resulted in the MHC and mATPase classification scheme that is currently used (Staron & Johnson, 1993). Histochemical fiber typing does not represent the exact amount of any one type of MHC in the fiber, as each fiber can contain more than one form of myosin in different amounts. However, electrophoretically assessed MHC content has demonstrated a correlation with histochemical mATPase fiber type in muscle biopsy samples (Fry et al., 1994) and single fiber analysis (Staron et al, 1991; Staron & Hikida, 1992). And although MHC is the major determinant of shortening velocity, myosin light chains may also contribute to contractile velocity (Staron & Johnson, 1993).

Briefly, in human muscle there are 3 major fiber types: I, IIa, and IIb identified through histochemical ATPase, correlated with electrophoretically identified myosin heavy chain (MHC) MHC I, MHCIIa and MHCIIb (Staron & Hikida, 1992). Other histochemical fiber types (Ic, IIc, IIac, IIab) have also been observed through ATPase histochemistry and coexpress the different amounts of the 3 MHCs (Staron & Hikida, 1992).

It has been suggested that type II fibers may possess a higher specific tension than type I fibers (Jones et al., 1989; Ryushi et al., 1988; Tesch & Karlsson, 1977; Young, 1984). The use of indirect studies of motor units has shown some proof of such type specific tension differences (FF > S) (Bodine et al., 1987; McDonagh et al., 1980). But studies of whole (Close, 1972) and single human fibers (Fitts et al., 1989) have found specific tension not to be significantly different between type I and type II muscle or muscle fibers. The interpretation of the results becomes more difficult since a recent study by Larsson and Moss (1993), comparing MHC composition in chemically skinned and freeze dried fibers, demonstrated that different techniques produced different results in maximal and specific tension. Type I and IIa fibers had lower maximal and specific tension in freeze dried, compared to chemically skinned, fibers while the type IIb fiber number was too low to make statistical comparison. Specific tension in chemically skinned fibers did not differ between fiber types, while in freeze dried fibers it varied according to MHC content, with IIb fibers having significantly greater specific tension than type I fibers. Type IIa fibers were not different from either. The authors could not discern a satisfactory explanation for the fiber type or preparation difference observed (Larsson & Moss, 1993). The difference between the motor unit and skinned muscle fiber measurement techniques, is that motor unit force is not measured directly in the former. Motor unit force is measured at the tendon, so the connective tissue between the fiber and tendon may affect the resulting force output (Enoka, 1994). In light of this information, if all other things are equal (muscle fiber pennation, amount of connective tissue, sarcoplasmic reticulum quantity and fiber length) a muscle with a higher percentage of type IIb fibers should be able to contract with a higher velocity, and possibly higher force output (Staron et al., 1994). This has yet to be confirmed.

1.4.4.6.2 ADAPTATIONS TO HEAVY RESISTANCE TRAINING

Early studies on fiber type with resistance training revealed no significant change in the percentage of type I or II fibers (Costill et al., 1979; Gonyea, 1980; MacDougall et al., 1980; Thorstensson et al., 1976). It was not until Staron et al. (1989), in a 20 week study involving women who performed leg exercise 2 times per week, that a fiber type shift was demonstrated. The significant decrease in type IIb fibers with a concomitant increase in type IIa fibers which was found (Staron et al., 1989), had previously only been observed with endurance training (Anderson & Henricksson, 1977; Baumann et al., 1987; Green et al., 1979; Ingjer, 1979; Jansson & Kaijer, 1977). Since then, this conversion (IIb→IIa) has been replicated with long term (+18 wk) (Adam et al., 1993; Colliander & Tesch, 1990; Hather et al., 1991; Wang et al., 1993) and short-term (6 wk) (Staron et al., 1991) heavy resistance training. This conversion has been shown to occur as early as 2 weeks of training, or after just 5 lifting sessions, and is supported by shifts in MHC (IIb→MHC IIa) (Staron et al., 1994). Further support for type IIb→IIa fiber conversion comes from studies of bodybuilders who possess a very low percentage of type IIb fibers (Essén-Gustavsson & Tesch, 1990; Klitgaard et al., 1990; Schantz & Kallman, 1989). In an attempt to observe the separate effects of eccentric (ECC) and concentric (CON) training, Hather et al. (1991) trained 3 groups of subjects with either CON/ECC, CON/CON or CON only and also showed a IIb→IIa conversion in all groups. They suggested that this conversion appears to be the result of the CON actions or simply contractile activity of any kind (Hather et al., 1991).

Increases in the percentage of type I fibers has also been observed (Sale et al., 1990; Staron et al., 1991). The conversion to type I fibers does not seem to be as well accepted and may be due to small sample size and/or no control group (Staron et al., 1991). In the study by Sale et al. (1990) high repetitions (15-20 reps) were used, providing more of an endurance component to the resistance training than other studies, which may have assisted in a type II→I fiber shift (Sale et al., 1990). Endurance training has been shown to cause an increase in type I fibers (Howald et al., 1985).

1.4.5.6.3 ADAPTATION TO BALLISTIC TRAINING

The effects of high velocity training on possible fiber type conversion is less clear than with heavy resistance training. Early studies using sprint training reported no significant change in type I and II fiber composition (Saltin et al., 1976; Thorstensson et al., 1975). In contrast, Jansson et al. (1990) had 2 groups of subjects perform either 30 s or 15 and 30 s maximal cycle ergometer sprints 2-3 times per wk, for 4-6 weeks; type I fibers decreased, while an increase in type IIa fibers was observed. Another study with subjects performing 10 s sprints for 6 weeks induced a similar fiber transformation, with the addition of a reduction in IIb fibers (Esbjornsson, et al., 1993). Anderson et al. (1992) studied elite sprinters from a 1 month layoff through 3 months of intensive training, and found a significant decrease in fibers containing MHC I and coexpressing MHC IIa/IIb fibers, with a significant increase in MHC IIa. Others have reported an increase in type I fibers following sprint training (Cadefau et al., 1990). Allemeier et al. (1994) replicated Jansson et al.'s (1990) study and did not find a type I → II shift, but a type IIb→IIa conversion (MHC analysis) similar to what has been shown before (Jacobs et al., 1987).

Although there are conflicting reports with sprint cycling, a briefer non-repetitive stimulus may not provide a long enough duration of muscle activity for fiber conversion to occur. Subjects performing only 5 s sprints showed no fiber type conversion (Thorstensson et al., 1975). It may be that a lack of activity is the only way to increase the percentage of the fastest contracting fibers. In support of the lack of activity, detraining (Wang et al., 1993) increases the percentage of IIb fibers.

Sprint training, although performed at a high velocity, may not show the same effects as single maximal ballistic efforts. Sprint cycle training is a repetitive movement and although the loads used for testing (~75g/kg body mass) are quite small and the velocity moderately high (knee joint angular velocities of 240°/s, cycling at 110 rpm), the duration of muscle action is long when compared to single maximal ballistic efforts reaching 360°/s average movement velocities, and 600°/s + peak velocities. Typical reps of single ballistic movements might only last ~ 250 ms, and when even a large number of reps and sets (10x10) are performed, only 5 s of activation might occur. Therefore, studies are needed to compare these forms of efforts to repetitive efforts. The use of sets and reps to equate volume of training can be misleading and overall activation time may need to be considered.

The only comparisons of the effects of fast and slow actions on changes in fiber type have used isokinetic training. This same problem may exist as with cycling with the upper limits of velocities used in training being only ~50% of maximum (Thorstensson et al., 1976; Froese & Houston, 1985). No significant fiber type conversion occurred between any of the 3 major fiber types with slow (1.05 rad s^{-1}) or fast (4.19 or 5.24 rad s^{-1}) isokinetic leg training for 6 or 10 weeks (Coyle et al., 1981; Ewing et al., 1990). However, another study did show an increased percentage of type IIa fibers, but with no significant change in any other fiber type (Côté et al., 1988).

1.4.4.6.4 POSSIBLE REASONS FOR FIBER CONVERSION

Fiber types are believed to be determined by two main factors: 1) "Neurotrophic" influences, 2) and the amount and pattern of muscle activity (stimulation frequencies received from the α-motor neuron by the muscle). Neurotrophic influences are unknown chemical substances released by the nerve soma and delivered to the muscle by axonal transport. While there is some evidence to support the existence of neurotrophic substances, their identity or exact effect on muscle is still unclear (Jolesz & Sreter, 1981). As mentioned previously (section 1.2) fast motor units can discharge with much higher frequencies than slow motor units during ballistic actions, but can not sustain these frequencies. Heavy resistance training initially produces low discharge frequencies but as the relative load increases higher frequencies can be attained and also, type IIb fibers will be recruited. The duration of one repetition may last seconds, whereas ballistic actions with last only a few hundred milliseconds. It may be that the type IIb fibers are not active long enough to cause conversion to either a faster or slower fiber, while the duration and frequency heavy resistance training employs either provides the correct neural activation, duration, or load necessary to cause conversion. Support can be observed in the training specific increase in muscle and fiber area, with heavy resistance training being the most effective stimulus.

Fiber type conversion requires that the coding gene for one contractile protein (slow myosin, slow-type regulatory proteins) be shut off, and the coding gene for another contractile protein be activated (Edstrom & Grimby, 1986). Since changes in gene expression are required to transform one fiber type into another, it has been hypothesized that whatever the stimulus is, it must be strong (Wong & Booth, 1990).

Animal studies have already demonstrated that high or low frequency stimulation can change muscle contractile properties, such that a slow muscle becomes faster (Lomo et al., 1974; 1980) and a fast muscle becomes slower (Salmons & Vrbová, 1969), respectively. Although these studies represent the extremes, human ballistic training may provide a way to convert fiber types, so skeletal muscle can increase its ability to generate maximum power and velocity in limb movement.

Though it would seem detrimental to reduce the percentage of type IIb fibers in power athletes through sprint and heavy resistance training, higher oxidative IIa fibers may allow more efficient training and recovery between efforts. The oxidative capacity of type IIa fibers has been shown to be higher than that of IIb fibers (Staron et al., 1983). Some evidence suggests that type IIb fibers (Wang et al., 1993) and Vmax (Fitts et al., 1989) can be increased towards baseline levels after a short detraining period. It may be possible that a taper period with only maximal brief efforts will allow an increase of IIb fibers back to pre-training levels, while still maintaining muscle hypertrophy and power for competition.

The functional advantage of one fiber type over another for high velocity power performance has yet to be determined. Fitts et al. (1989) showed no decrease in 22.9 m swimming sprint time after a 54% decrease in type II fiber Vmax after 10 day of intensified swim training in collegiate swimmers. However, other factors may be involved, such as mechanical efficiency and the fact that such an activity contains an endurance component that allows the maintenance of performance (Fitts et al., 1989). Also, muscle shortening in sprint cycling has been calculated to not go beyond 20% of isolated muscle V_{max} (Bigland-Ritchie cited in Faulkner, 1986). So it may be that, in ballistic movements, even though attaining maximal limb velocity, the muscle V_{max}, which is a representation of all the fibers, is not attained. To date, single fiber V_{max} analysis has not been conducted in humans following ballistic or heavy resistance training.

In summary, most heavy resistance training programs demonstrate subpopulation fiber type shifts (IIb→IIa), while high speed training produces conflicting results, in that both increases and decreases in IIb fibers have been found. To the author's knowledge no study has examined the effects of single effort ballistic training on muscle fiber type. It is possible that such a training program could affect the fiber type distribution differently than has been seen in the studies conducted to date.

1.4.4.7 ULTRASTRUCTURE

The contractile material of muscle is made up of muscle fibers composed of myofibrils, sarcoplasmic reticulum, mitochondria, glycogen granules, lipid droplets and the "cytoskeleton". Myofilaments (myosin and actin) make up about 80-83% of the myofibril (Alway et al., 1988, 1989; MacDougall et al., 1982; Wang et al., 1993). MacDougall (1986) showed that the increases in fiber area following heavy resistance training are due primarily to increased size and number of myofibrils with no change in the myofilament packing density. Electron microscopy analysis revealed that actin and myosin filaments increased in number on the periphery of the myofibril. Fiber area increased by 31% with only a 16% increase in myofibril area suggesting that myofibril size and numbers also increased (MacDougall, 1986). A recent study by Wang et al. (1993) supports this observation of an increase in myofibril number as the cause of increased fiber area following heavy resistance training.

Increased packing density of fibers, but not myofibrils or filaments, could occur through the loss of adipose and connective tissue, or increased packing density of muscle fibers or their myofibrils (Jones et al., 1989). Evidence for loss of connective tissue and fat is not available, but, indirect evidence of greater fiber density comes from the increase in fiber area of 15-20% with only a 5-10% increase in muscle ACSA (Jones et al., 1989). It is possible, however that these differences may be due to methodological error variations inherent to small sample size and variations in location of the muscle sample taken by needle biopsy.

Mitochondrial volume density has been shown to decrease (Alway et al., 1990c; MacDougall et al., 1979; Lüthi et al., 1986) or not change at all (Wang et al., 1993) following weight training. The discrepancy between Wang et al. (1993) and others may be due to the use of different sexes. Another possibility put forth by the authors was that with selectively more hypertrophy in some fibers, a discrepancy in the interpretation of mitochondrial volume changes per unit area of the electron micrograph sections analyzed might account for the differences (Wang et al., 1993). A lower mitochondrial density in experienced heavy resistance athletes compared to untrained controls strengthens the results seen following training studies (Alway et al., 1988; MacDougall et al., 1982). Lipid density has been shown to increase (MacDougall et al. 1979) in triceps muscles, but remain the same after heavy resistance training of quadriceps muscles (Luthi et al., 1986; Wang et al., 1993). Volume density of sarcoplasmic reticulum and t-tubules also does not appear to be affected by resistance training (Alway et al., 1988; 1990c). No clear conclusion can be made about cytoplasmic space either, as cross-sectional studies of bodybuilders have shown greater (MacDougall et al., 1984) and no difference (Alway et al., 1988) compared to untrained subjects. To the author's knowledge no investigation has been undertaken on the effects of single ballistic actions on muscle ultrastructure.

1.4.4.8 CAPILLARY DENSITY

Capillary density has been shown to increase (Staron et al., 1989) or not change (Luthi et al., 1986; Tesch et al., 1983; Tesch et. al., 1990; Wang et al., 1993) following heavy resistance training. The discrepancy between the studies, may be due to the variable duration of the studies (Tesch, 1992). Also in support of a dilution of the capillaries due to increased muscle size with assumed no capillary neoformation, is the lower capillary density observed in bodybuilders and powerlifters compare to untrained individuals (Tesch et al., 1984). When comparing bodybuilders to lifters, bodybuilders exhibited a greater capillary density, suggesting that employing a higher number of repetitions and sets than lifters, may cause the development of new capillaries (Tesch, 1992). It is possible that genetic disposition caused the selection of individuals predisposed to better performance in each kind of training. To the authors knowledge no study has investigated alterations in capillary density following single maximal ballistic actions, and in light of the differences observed following heavy resistance training, the much less aerobically taxing ballistic training would not be expected to have an affect.

1.4.4.9 CONNECTIVE TISSUE

Edomysial connective tissue has been shown to be stimulated following strength training in young men (Brzank & Peiper, 1986 cited in Stone, 1992). The increase appears to be relative to the muscle mass, as a study by MacDougall et al. (1984), comparing bodybuilders and untrained individuals, determined that in both groups non-contractile tissue made up approximately 13% of total muscle volume, with ~6% from interstitial connective tissue and ~7% from other sources. So, although the relative connective tissue content remains the same, weight training appears to increase the total amount of connective tissue. The overall increase in connective tissue may represent greater muscle sheath strength (Stone, 1992). Others have postulated that training may cause new connective tissue attachments (besides those at the proximal and distal ends) between the middle of muscle fibers and the tendon, (see Figure 11 in Jones et al., 1989). The effect of such new attachments may be to increase the specific tension of the muscle (Jones, et al., 1989). This theory has yet to be proven. Again, to the author's knowledge, no investigation has examined the effects of ballistic action training on the amount of connective tissue in muscle.

1.4.4.10 SPECIFIC TENSION

As mentioned in the previous section (1.4.4.6) specific tension is the maximum force (tension) that can be generated per unit cross-sectional area of muscle. Although it is still not clear if there are fiber type differences in specific tension, if type II fibers were to have a higher specific tension, their selective hypertrophy would not only be advantageous for their superior speed of contraction, but also their greater force output, thus improving muscle power. An increase in specific tension would allow a much greater increase in force relative to muscle size. In activities where the human body or limb mass must be projected against gravity, or sports with body weight restriction, this adaptation would allow superior performance.

Heavy resistance training has been reported to increase (Jones et al., 1989; Narici et al., 1989; Rutherford & Jones, 1992) and decrease (Maughan, 1984; Kawakami et al., 1995) specific tension following muscle hypertrophy. Cross-sectional data of bodybuilders and weightlifters has demonstrated a reduction of torque at high velocities (Tesch & Larsson, 1982). Evidence for a decrease in specific tension was demonstrated in a study by Sale et al. (1992) where after training an increase in muscle size was observed without an increase in strength. Compensatory hypertrophy in rats also produced the same effect and it was determined that the deficit is not due to disproportionate changes in contractile or noncontractile tissue (Kandarian & White, 1989; 1990). Why might specific tension decrease? An increase in muscle pennation angle would decrease the force by altering the direction of force exerted by the muscle fibers on the tendon. Another possibility for a decrease is that increased hypertrophy may impair excitation-contraction coupling calcium delivery to the contractile proteins (Kandarian & Williams, 1993). No study has investigated the effects ballistic training has on muscle or fiber specific tension. Fiber specific tension adaptations need to be studied in heavy resistance training also.

The previous sections on skeletal muscle adaptations still leave the debate of whether it is better to increase the speed or size of the muscle. In terms of the performance of athletic activities, biomechanical modeling of the vertical jump has suggested that either increasing the size or speed of the muscle are equally effective (Pandy & Zajac, 1989, Pandy, 1990), and that increasing muscle size is more important (Zajac, 1993). To date no study has looked at this issue by inducing either muscle hypertrophy or increased velocity of shortening.

1.5 SUMMARY

Ballistic and heavy resistance actions are defined by the characteristics they exhibit. Ballistic actions have the shortest movement time, moderate peak force, and highest velocity, acceleration, and power output. Heavy resistance actions are generally performed slowly with large external loads, resulting in the highest peak force, low velocity and acceleration and moderate power output. Rate of force development, although having the potential to be high in fast heavy resistance actions, is considerably less than in ballistic actions when the commonly slow movement is performed. Effective loads for heavy resistance training are above 60% of 1 RM (MacDougall & Sale, 1981), whereas ballistic training loads generally range between 0 and 30% of maximum contraction force (Bauer et al., 1995; Wilson et al., 1993).

Motor control defines ballistic movements as being preprogrammed actions with no sensory feedback and heavy resistance movements under constant peripheral feedback (Desmedt & Godaux, 1979). It is believed that different higher brain structures contribute to the control of these actions. It is still unclear if selective recruitment of fast motor units occurs during high speed movements, since studies are conflicting and the analysis techniques make interpretation difficult. Firing rates have been suggested as the main control of power output in ballistic actions. The high frequency bursts (100 Hz) observed at the onset of ballistic actions are much higher than the frequencies (50 Hz) during maximal heavy resistance actions. Muscle activation patterns also demonstrate the difference between the two actions. Besides the dramatic difference in the length of activation, both may display a continuous pattern with antagonist coactivation, but only the ballistic actions may give rise to a triphasic pattern and selective activation of predominately fast muscle.

Heavy resistance and ballistic actions provide different mechanical and neural training stimuli that can result in adaptations in performance and the neuromuscular system that may be unique to the mode of training. Both training modes improve athletic motor performance. However, the combination of the two training techniques has proven to be more effective than either alone. Ballistic training is slightly more effective in enhancing kinetic and kinematic performance emphasizing speed and power, whereas heavy resistance training has the advantage in improving isometric and low velocity concentric peak force.

The improvements observed in both athletic motor and kinetic and kinematic performance can be accounted for by muscle changes such as time and tension related evoked contractile properties, muscle fiber alterations, and altered neural drive to the muscles, seen most frequently in agonist EMG. Mixed results have been found in agonist EMG after heavy resistance training, while ballistic training does not appear to alter agonist EMG, unless in combination with heavy resistance training. Contractile properties are affected by both training programs, with ballistic training possibly decreasing the temporal contraction measures, while heavy resistance training showed the possibility of an opposite response, depending on the muscles trained. Most studies have focused only on agonist activation when studying neural adaptations, and it may be that antagonist coactivation and possibly intramuscular and intermuscular coordination may represent the adaptations that positively affect performance following both types of training. It is commonly known by coaches and athletes that heavy resistance training causes a larger increase in muscle and fiber size than ballistic training, and the minimal evidence to date would suggest that this is true. Heavy resistance training has shown fiber conversion from IIb to IIa subpopulations, but type I and type II fiber populations appear to be set primarily by either many years of training, which has not yet been tested, or genetic endowment. Other adaptations seen in muscle pennation, ultrastructure, capillary supply, and connective tissue have only recently been examined following heavy resistance training, while ballistic training in these areas has not been the investigated.

The key question for athletes and coaches is what training provides the largest benefit in the shortest amount of time. Although recent research has provided some answers as to what type of training may provide enhancement of mechanical properties and athletic performance, there is still controversy regarding which method provides the best results for the parameters responsible for improved performance (velocity, power, peak torque, etc.). The adaptations in the neuromuscular system causing these enhancements in performance are even less clear. Future research should focus on what mechanical performance characteristics are improved by each type of training and how alterations in the neuromuscular system are providing this improved performance. The use of single joint actions may also help reduce the learning effect and provide less variability, often seen in multi-joint actions.

Table 1. Motor unit and muscle fiber types

Motor Unit	**Fiber types in motor unit**	**Twitch force**	**Twitch contraction time**	**Fatigability**	**Recruitment order**
Fast fatigable (FF)	Fast glycolytic (FG), IIb	High	Fast	High	3rd
Fast fatigue-resistant (FR)	Fast oxidative glycolytic (FOG), IIa	Medium	Medium	medium	2nd
Slow (S)	Slow oxidative (SO), I	Low	Slow	low	1st

Table 2. Effects of ballistic and heavy resistance training on isometric evoked contractile properties in skeletal muscle

Muscle	Exercise	Peak Torque	MRFD	Contraction Time	½ RT	Reference
Heavy Resistance training						
Triceps surae	Isometric	No change *	—	No ch./decr.	—	Davies & Young, 1983
Triceps surae	Isometric	No change	Increased	Decreased	No change	Alway et al., 1989
Triceps surae	Isometric	No change			Increased	Kitai & Sale, 1989
Triceps surae	Isometric	No change	No change†	Decreased	No change	Alway et al., 1990
Hypothenar	Isometric/WT	Increased *	No change	Decreased	No change	Liberson & Asa, 1959
Adductor pollicis	Isometric	Increased *	No change	No change	No change	Duchateau & Hainaut, 1984
1st Dorsal Int.	Isometric	Increased	—	No change	No change	Keen et al., 1994
Elbow flexors	Isometric	No change *	—	No change	No change	McDonagh et al., 1983
Elbow flexors	Weight training	Increased	Increased	No change	Increased	Brown et al., 1990
Elbow flexors & Knee extensors	Weight training	Increased	—	No change	No change	Ramsay et al., 1990
Elbow extensors	Weight training	Increased	No change	Increased	No change	Rice et al., 1993
Ballistic training						
Adductor pollicis	concentric	Increased *	Increased	Decreased	Decreased	Duchateau & Hainaut, 1984
Elbow extensors	concentric	Increased	Increased	No change	No change	Bauer et al., 1995
Tibialis anterior	Isokinetic/ Isometric	No change *	No change *	Decreased	Decreased	Behm & Sale, 1993

The terms no change, decreased, and increased are relative to pre-training values. Isokinetic in one arm , weight training in the other (Isokinetic/WT). * Tetanus and twitch, *MRFD* = Maximum rate of force development, *½ RT* = ½ Relaxation time, Contraction time, and time to peak torque are used interchangeably, † Average RFD, No ch./Decr.= No change following 100% MVC, but decrease during 30% MVC training in CT.

Table 3. Cross-sectional data of different athletes' muscle and fiber size

Athlete	Muscle	Muscle size	Fiber Size		Reference
			Type I	Type II	
Bodybuilders	Vastus Lateralis	Larger	No difference	Larger[+]	Schantz et al., 1983
Weightlifters	Vastus Lateralis	Larger	Larger	Larger	Schantz et al., 1981
Bodybuilders	Vastus Lateralis/Delts	Larger	No difference	No difference	Tesch & Larsson, 1982
Bodybuilders	Biceps Brachii	Larger	No difference	No difference	MacDougall et al., 1984
Sprinters	Vastus Lateralis	No difference	No difference	Larger *	Costill et al., 1976
BB & PL	Triceps Brachii	Larger	No difference	No difference	MacDougall et al., 1979
BB & PL	Triceps Brachii	Larger	No difference @	No difference @	MacDougall et al., 1982
Weightlifters	Vastus Lateralis/Delts	Larger	No difference	Larger	Prince et al., 1976

Larger or No difference refers to athletes compared to untrained controls, unless special character makes other distinctions. BB & PL - Bodybuilders and powerlifters. [+] Larger type IIa/I ratio compared to active controls. * Elite sprinters compared to other track athletes. @ Compared to non-strength trained "normals" before and after their heavy resistance training.

Chapter I: Figure Legends

Figure 1. Load-velocity (□)/power (●) curves of a ballistic elbow extension, demonstrating the approximate range of loads used during ballistic and heavy resistance training (Top panel). Load-torque(■)/ movement time (○) curves further demonstrate the difference between the two training actions (Bottom panel). Actions were performed on a specially designed arm apparatus, where the forearm was strapped to an aluminum brace. A steel shaft was mounted to the center of rotation of the forearm brace and a wheel acting as a pulley to lift a weight equivalent to a percentage of the subjects MVC. The subject was tested at 10% increments from 0%-100% MVC. The power curve (right vertical axis) was derived from torque (N·m) and velocity (rad·s^{-1}).(unpublished data).

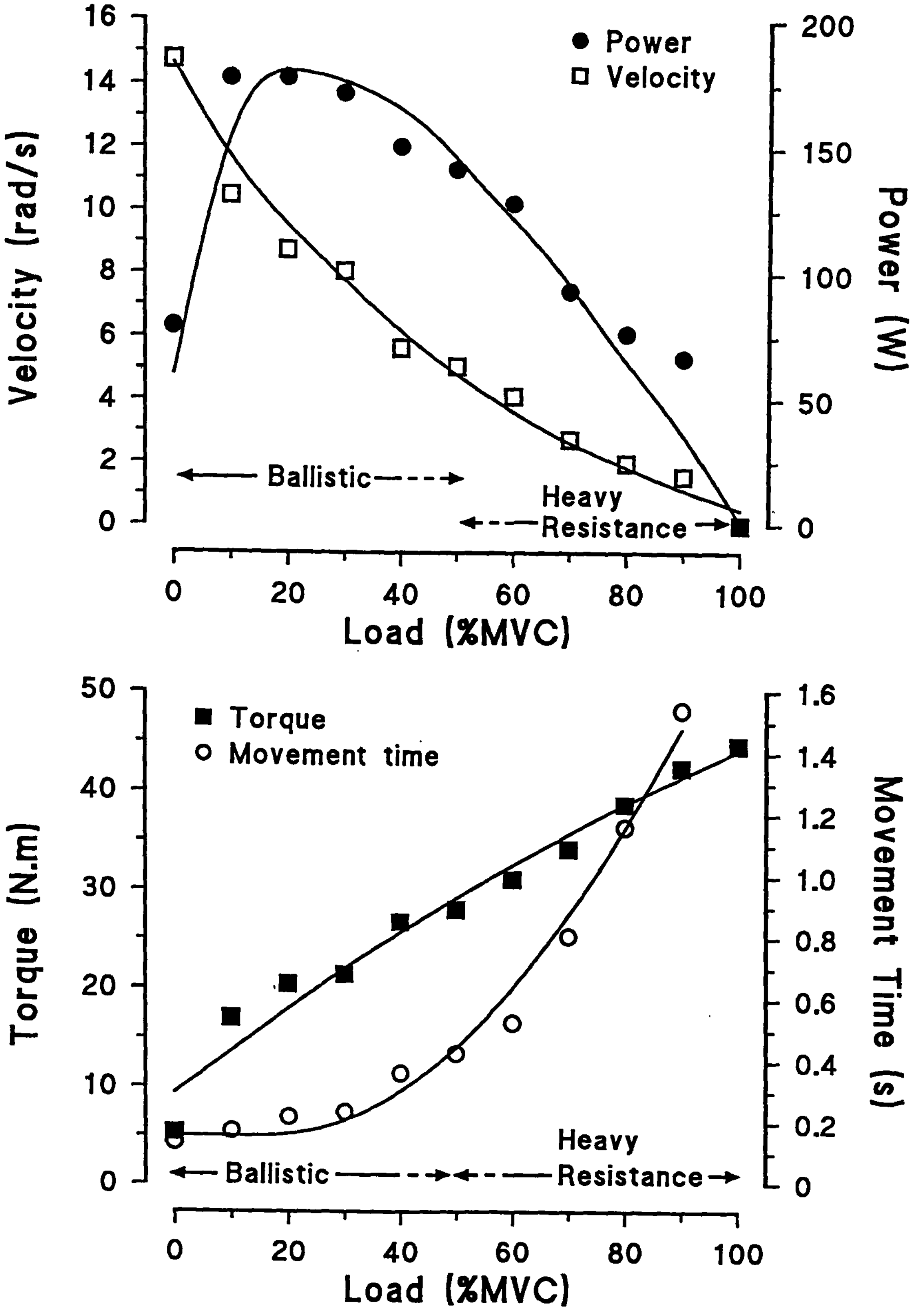
Figure 2. Torque, rate of torque development (RTD) velocity, acceleration, and power recordings form ballistic (10% MVC) and heavy resistance (85% 1 RM) elbow extension. Observe that the ballistic action was recorded over a shorter time scale (~.500 s) than the heavy resistance action (~2.4 s). Ballistic actions were performed on the same device as in Figure 1 with a load equivalent to 10% of the subject's MVC. Heavy resistance actions were performed from an over the shoulder wall mounted pulley system with an 85% 1 RM load (unpublished data).

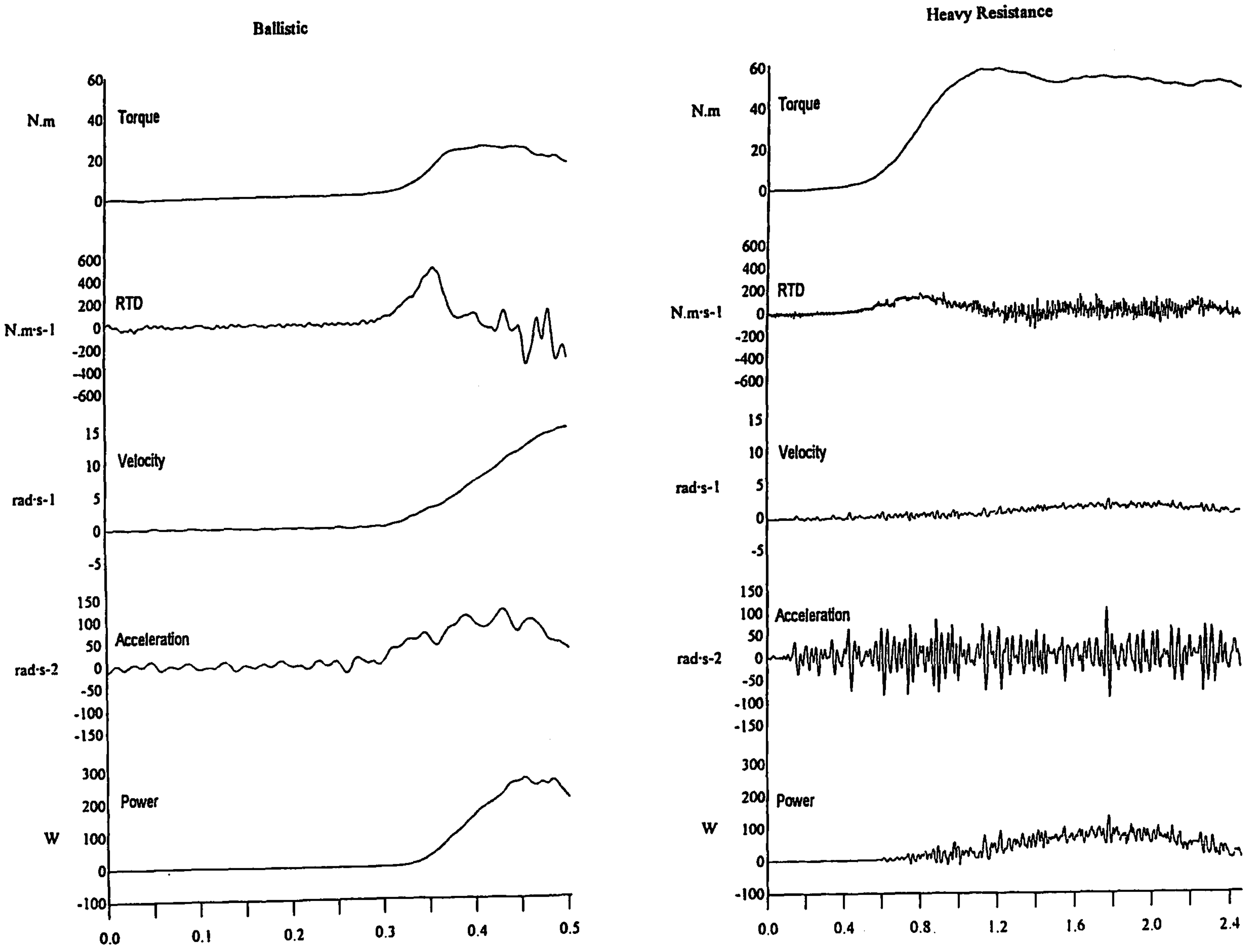
Figure 3. Torque, RTD, velocity, acceleration, and power recordings from an "explosive" heavy resistance (85% 1 RM) elbow extension performed as fast as possible. The time scale for the action was 1.1 seconds. The same device was used as the heavy resistance action in Figure 2. The heavy resistance device was not as restricting as the ballistic apparatus to extraneous movement, and other muscle groups may have contributed to the measurements values (unpublished data).

Figure 4. Torque and electromyographic (EMG) recordings from agonist (extensors-triceps), and antagonist (flexor-biceps) muscles during heavy resistance (85% 1 RM) and ballistic (10% MVC) elbow extensions. Same devices for both actions as in Figures 1 & 2. A long (Fig. A) and short (Fig. B) time line demonstrate the large differences in the time of action and muscle activity. Note the constant burst activity pattern during both actions, but the much more abrupt onset of the ballistic action (unpublished data).

Figure 5. Evoked isometric twitch torque recording with measurements of twitch peak torque (PT), maximum rate of torque development (MRTD), maximum rate of torque relaxation (MRTR), and torque-time integral (impulse). PT established as the highest torque reading. MRTD and MRTR were taken as the mean of two points on the torque curve given the highest slope value. Impulse (area under curve) starts when 2% of PT is reached upon the rise of the torque, and ends when 2% of PT is reached on the decent phase of the torque trace (unpublished data).

Figure 6. Evoked isometric twitch torque recording with measurements of time to peak torque (TPT), rise time (RT), and ½ relaxation time (½ RT) displayed as would be analyzed. Rise time defined as the time from 10%-90% of PT. TPT starting at 2% of PT and ending at PT. HRT defined as the time from PT to half of the peak torque value upon the decent of the torque tracing (unpublished data).


Velocity (rad/s)
16
14
12
10
8
6
4
2
0
● Power
□ Velocity
200
150
100
50
0
Power (W)
Ballistic
Heavy
Resistance
0
20
40
60
80
100
Load (%MVC)
Torque (N.m)
50
40
30
20
10
0
■ Torque
○ Movement time
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Movement Time (s)
Ballistic
Heavy
Resistance
0
20
40
60
80
100
Load (%MVC)


Ballistic
Heavy Resistance
N.m
Torque
60
40
20
0
N.m·s-1
RTD
600
400
200
0
-200
-400
-600
rad·s-1
Velocity
15
10
5
0
-5
rad·s-2
Acceleration
150
100
50
0
-50
-100
-150
W
Power
300
200
100
0
-100
0.0
0.1
0.2
0.3
0.4
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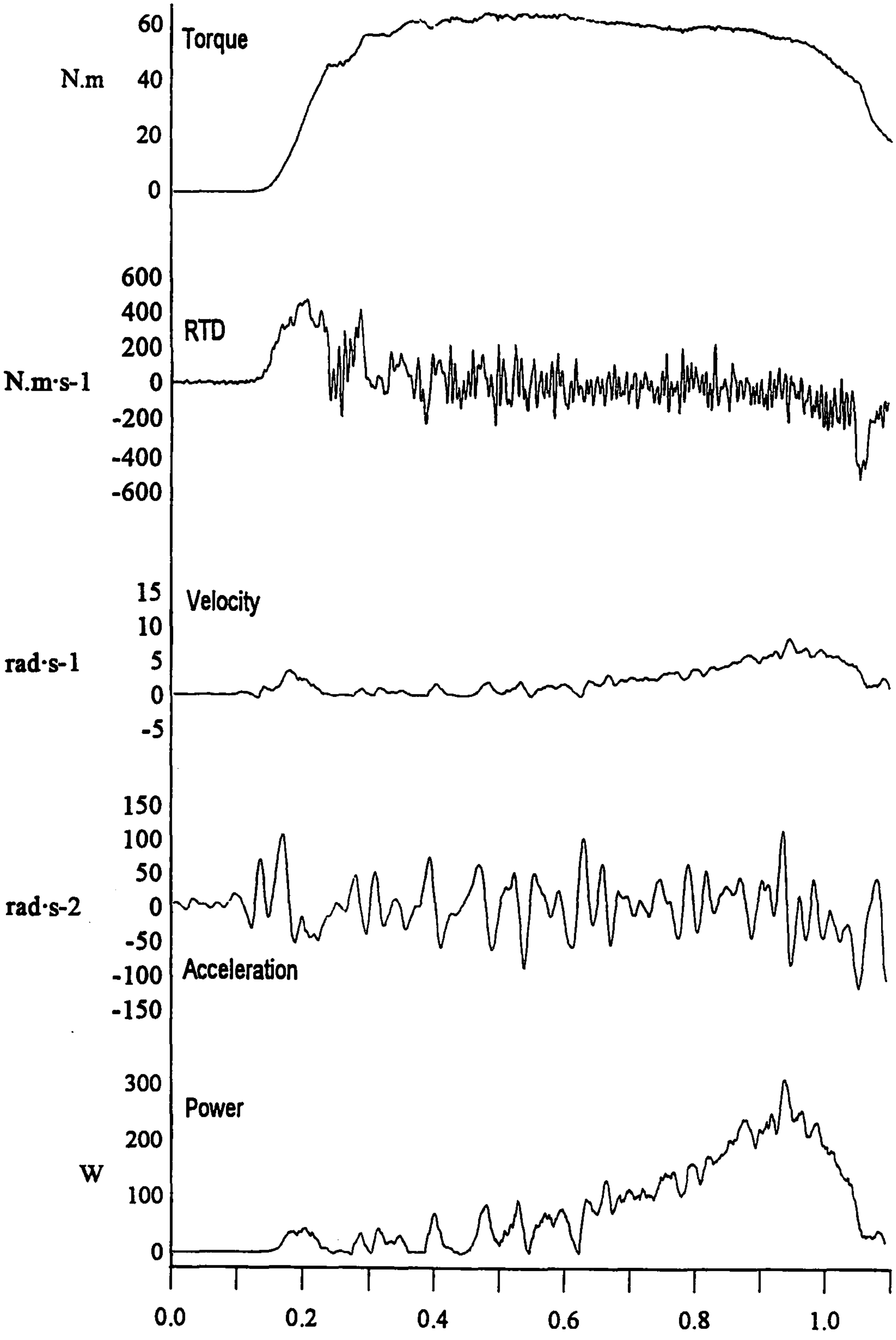
0.4
0.8
1.2
1.6
2.0
2.4

Figure 2/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Torque
N.m
40
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400
RTD
200
N.m·s-1
0
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-400
-600
15
Velocity
10
rad·s-1
5
0
-5
150
100
50
rad·s-2
0
-50
-100
Acceleration
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300
Power
200
W
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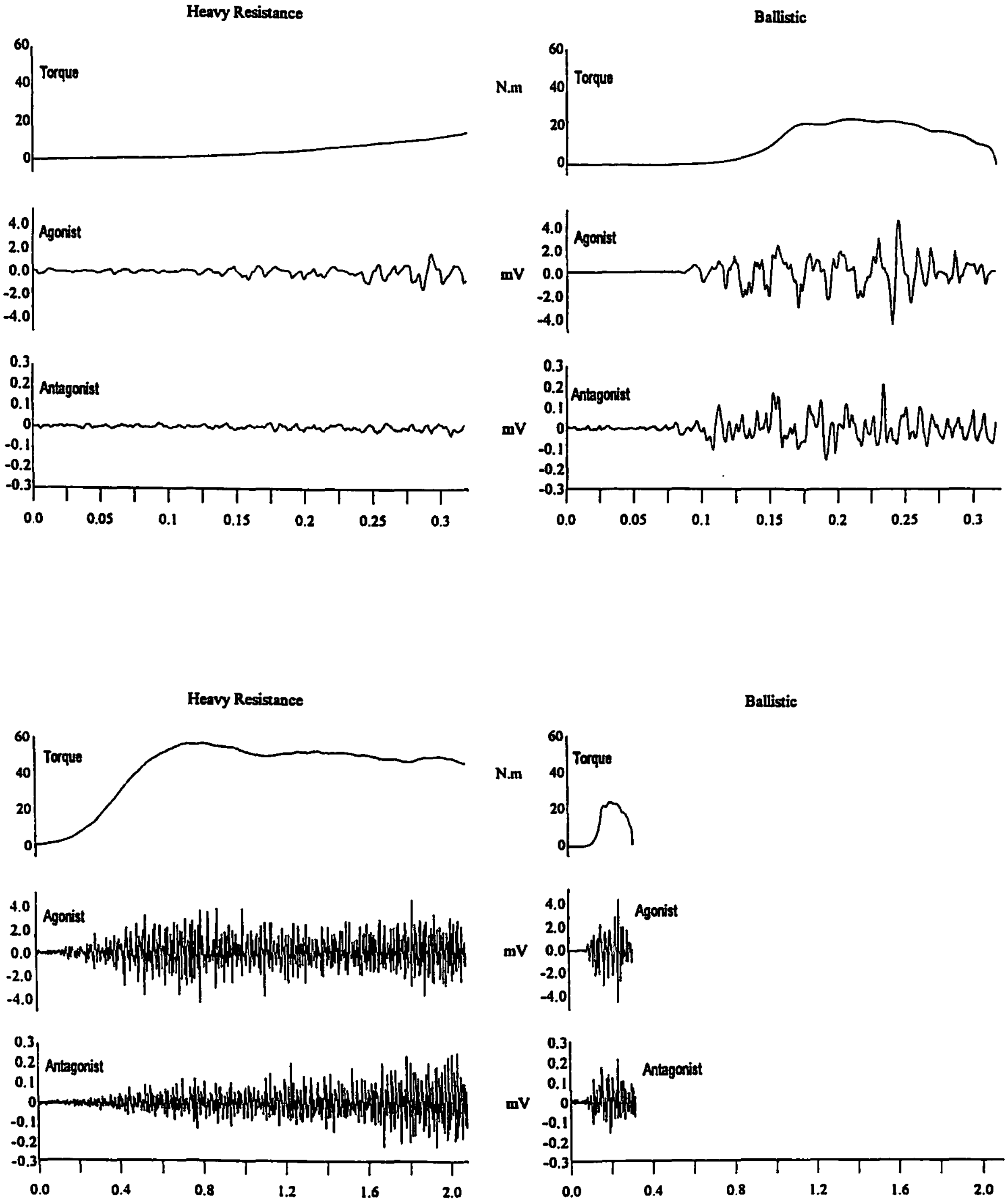
Figure 4/


Heavy Resistance
Ballistic
Torque
Agonist
Antagonist
N.m
mV
60
40
20
0
4.0
2.0
0.0
-2.0
-4.0
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0.0
0.05
0.1
0.15
0.2
0.25
0.3
Heavy Resistance
Ballistic
Torque
Agonist
Antagonist
N.m
mV
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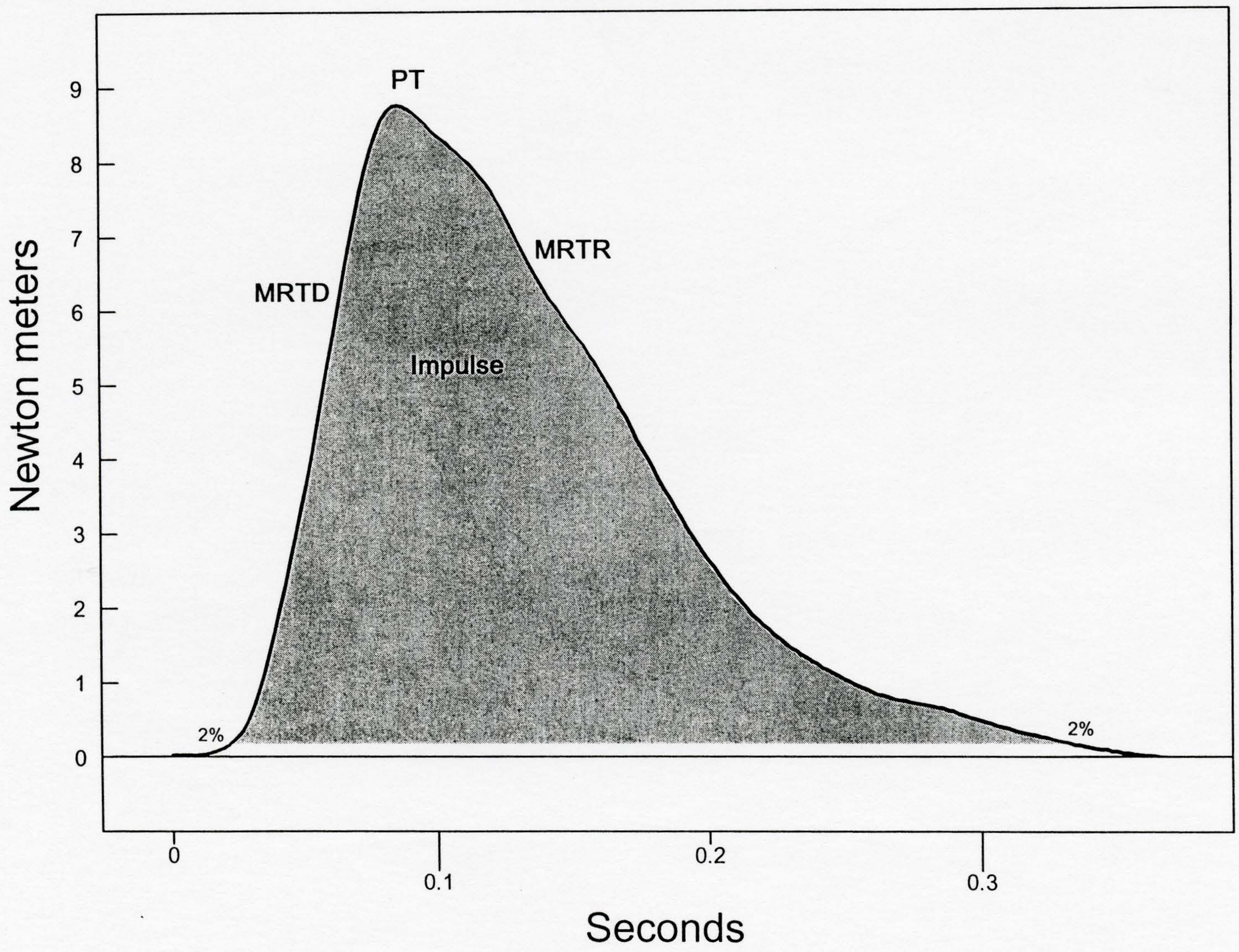
1.2
1.6
2.0


PT
MRTD
MRTR
Impulse
2%
2%
Newton meters
0
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2
3
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6
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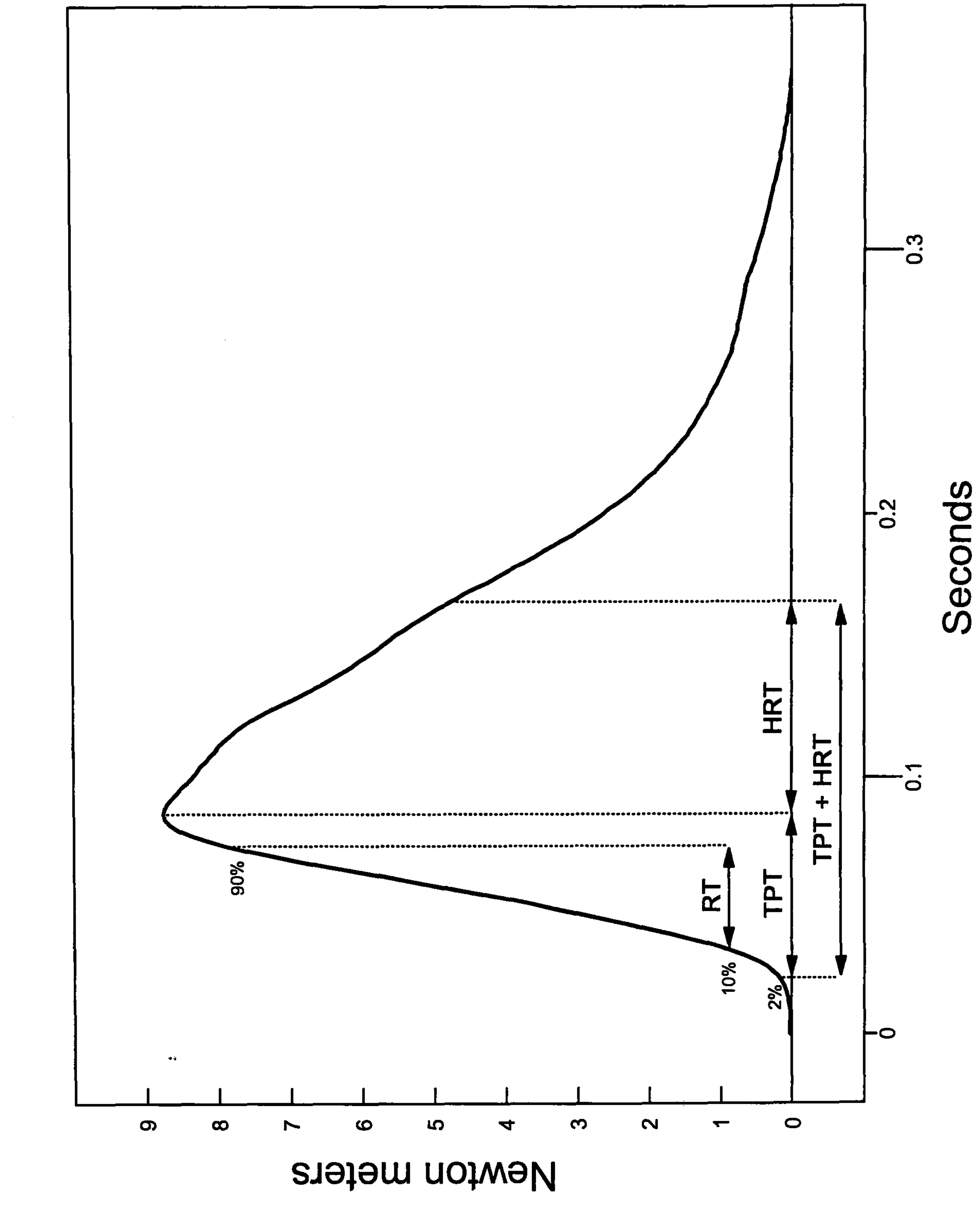
9
Seconds
0
0.1
0.2
0.3

Figure 6/ 66


Newton meters
0
1
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3
4
5
6
7
8
9
Seconds
0
0.1
0.2
0.3
2%
10%
90%
RT
TPT
HRT
TPT + HRT

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CHAPTER II

PERFORMANCE AND NEUROMUSCULAR ADAPTATIONS TO HEAVY RESISTANCE AND BALLISTIC TRAINING

2.1 INTRODUCTION

In striving for success, athletes and coaches design and implement training programs to improve performance. To maximize results, training must provide adaptations that develop increases in kinematic and kinetic variables related to performance of sport specific actions. Many sports, such as sprinting, kicking, throwing, hitting, and jumping, require a high degree of speed in combination with high forces, resulting in the need for maximum power. Power is the product of force and velocity, and represents a continuum with some actions requiring force to predominate, and others velocity. The concern for athletes and coaches is to use the optimal training program allowing maximum gains in performance in the shortest amount of time.

Research has been conducted on the two preferred and most popular methods for increasing speed and power: ballistic and heavy resistance training. Ballistic actions are characterized by a high velocity, low to moderate force output, maximal rate of force development (RFD), and high peak power. In contrast, heavy resistance movements have the highest forces, low velocity, low to moderate power, and generally low RFD. Control of these movements by the central nervous system also distinguishes ballistic (preprogrammed with no feedback) from heavy resistance (continuous feedback) actions (Desmedt and Godaux, 1979).

Heavy resistance training has been investigated more thoroughly than ballistic training, possibly because of the much larger changes observed during high load/low velocity movements as compared to low load/high velocity performance (Coyle et al., 1981). However, many coaches and athletes, in an attempt to closely mimic athletic performance according to movement pattern, load, velocity, and type of action (isometric, concentric, and eccentric), believe ballistic movements need to be employed to improve high velocity performance (Sale & MacDougall, 1981). Although studies have compared explosive (ballistic) actions to heavy resistance training (Adams et al., 1992; Berger, 1963; Newton & McEvoy, 1994; Wilson et al., 1993), and the combination of both training methods (Häkkinen et al., 1985b) to that of heavy resistance training alone (Häkkinen et al., 1985a), there is still debate as to which training program provides the greatest benefit (power) in high speed activities. Part of the confusion is that research conducted to measure force, velocity, and power is not done so under high velocity conditions. Most often isokinetic or isometric actions are recorded to compare adaptations of peak torque at high and low velocities or RFD is measured under isometric conditions to demonstrate a connection between these adaptations and those improvements made during high velocity athletic performance. However, neither of these measurements are common to dynamic athletic events (isotonic), and most actions are performed at much higher velocities than can be achieved using such devices.

The differences in the way these actions are controlled by the brain and the resulting muscular effort leading to different limb actions could presumably cause different neural and muscular adaptations. The changes occurring in the nervous system following training are still unclear since no change (Baker et al., 1994; Cannon & Cafarelli, 1987; Garfinkel & Cafarelli, 1992; Thorstensson et al., 1976; Weir et al., 1995) or increases (Häkkinen & Komi, 1983; Häkkinen & Komi, 1986; Häkkinen et al., 1985a;

Keen et al., 1994; Moritani & DeVries, 1979; Weir et al., 1994) in agonist EMG have been observed following heavy resistance training. Ballistic training has also shown no change (Häkkinen & Komi 1986) and an increase in agonist EMG, but only when combined with heavy resistance training (Häkkinen, et al., 1985b). Although increased activation of agonists could increase performance, so might a decrease in antagonist coactivation. However, as yet no training study has been undertaken to examine changes in coactivation between the two training modes. The large increases in muscle mass often only observed following heavy resistance training could provide increased force production that can not be realized by ballistic training. If the absolute peak force increases, the constant load needed to be accelerated in athletic activities would become relatively lighter, allowing a higher velocity and power to be developed.

Although fiber type conversions do not appear to occur from either training program, sub-population shifts have been observed in heavy resistance training from type IIb → IIa (Adams et al., 1993; Colliander & Tesch, 1990; Hather et al., 1991; Staron et al., 1989; Wang et al., 1993). How these changes may affect single maximal high velocity actions is not known. It therefore may be possible to shift the fiber type composition towards a faster contracting fiber with the opposite type of training, such as single ballistic efforts. This could provide a large benefit since type IIb fibers have been shown to have a maximal shortening velocity approximately three times faster than IIa fibers (Larsson & Moss, 1993). Most high velocity repetitive movement studies have not demonstrated increases in type II fibers (Saltin et al., 1976; Thorstensson et al., 1975), but sprint training has demonstrated a conversion from type I to type IIa fibers (Jansson et al., 1990) and also a shift of IIb to IIa fiber type (Esbjornsson, et al., 1993). Upon replication of Jansson et al.'s (1990) study of sprint cycling, Allemeier et al. (1994) did not find a type I to II shift, but a type IIb to IIa conversion. These high velocity actions are often used in athletics, but a single ballistic action may provide a better indicator of whether a conversion to a faster fiber type is possible, and if so, whether it enhances performance?

The purpose of the present study was to determine the unique and similar adaptations that heavy resistance and ballistic training induce, in terms of mechanical performance and related neuromuscular adaptations. The current study was a unique examination of ballistic and heavy resistance training, since to the author's knowledge no study has studied the differences between single joint ballistic and heavy resistance training analyzing ballistic, 1 RM and isometric single joint performance tests; and agonist and antagonist EMG coactivation, and fiber type conversion.

It was hypothesized that ballistic training would result in a greater improvement in ballistic performance and related adaptations than heavy resistance training. In contrast, heavy resistance training would cause greater increases in weightlifting and isometric strength, and the associated neuromuscular adaptations.

2.2 METHODOLOGY

2.2.1 SUBJECTS & EXPERIMENTAL DESIGN

Twenty male university students were assigned to either a training (n=10) (age 21.1 ± 1.0 y, height 177.8 ± 8.3 cm, mass 74.5 ± 11.4 kg) or control (n=10) (age 20.7 ± .9 y, height 177.4 ± 7.8 cm, mass 76.2 ± 9.9 kg) group. Additional anthropometric measures were made using a dual-energy x-ray absorptiometer (DPX) (Hologic DPX 1000 W Densitometer) presented in Table 1. Prior to the end of the study one training subject had an arm injury unrelated to the study, which did not allow post-training assessment. None of the subjects had participated in any form of resistance or explosive training 8 months prior to the study, and over the past 2 years had not trained in a consistent manner for more than a few months. Neither group was allowed to participate in any sport or exercise pattern that might affect muscles of the upper body activities during the duration of the study. Before signing the consent forms, subjects were informed orally and in writing about the scope and objectives of the study, in accordance with the Ethics Committee of McMaster University.

A random design was used to assign the dominant and non-dominant arms of the training group into either heavy resistance (HR) or ballistic (BL) elbow extension training. Following pre-testing, the training group trained 3 times per week for 17 weeks, with the order of training in a given week (BL→HR) reversed from the previous week (HR→BL) throughout the study. Training sessions were separated by at least one day of rest to allow recovery. A 2 week break occurred between the 6th and 7th week to accommodate the students' Christmas break (Fig. 1). To minimize the effect of detraining, an additional week of lesser volume and intensity was also included during the first week of post-testing. To assist in motivation and monitoring of progress, a record for the HR training was kept daily. In the BL training, feedback from either an oscilloscope or computer screen was available to the subjects every other week. The BL arm's peak torque values were also recorded during certain times throughout the study as seen in Figure 2, which shows the schedule of testing and training.

2.2.2 BALLISTIC (BL) TRAINING

2.2.2.1 BALLISTIC APPARATUS

Ballistic training and testing was done in a specially designed arm manipulandum (Fig. 3). Subjects sat in a vertically and horizontally adjustable chair with their upper arm supported in the horizontal plane by a padded portion of the apparatus' table top edge. Their forearm was velcro strapped in a neutral (mid supination-pronation) position to an aluminum brace allowing no extraneous movements of the elbow and forearm. The arm brace was perpendicular relative to the horizontal (90°) resulting in a starting elbow joint angle of 75-80° of flexion (full extension=180°). A shoulder joint angle of 90° along the horizontal plane, and 75-80° along the vertical plane was maintained by a large velcro strap placed diagonally across the chest crossing over the acromion process during testing and training. The forearm brace was attached to a steel axle mounted to a wood-steel frame. A locking clamp positioned around the axle maintained the forearm brace position during testing of MVCs. To provide a calibrated load, a weight stack was lifted from a resting platform by a cord attached to an alloy wheel centered over the axle. To prevent the weight's momentum from carrying it beyond the apparatus' rotational displacement, a restraining strap (surgical tubing) was attached to the bottom of the weight stack. Torque and displacement sensors mounted on the axle had signals amplified and fed into a 12 bit A/D converter (Dataq Electronics) and sent into a microcomputer sampling at 1495 Hz and operating CODAS data acquisition software (Dataq Electronics).

2.2.2.2 BALLISTIC TRAINING

Subjects voluntarily extended their elbow joint through ~85° range of motion into a foam pad (Century karate punching pad). With each repetition an attempt was made to reach maximal velocity and peak torque. Subjects were instructed to try to isolate their elbow extensor muscles in performing the concentric ballistic actions, thus avoiding extraneous movement of the shoulder. Subjects paused briefly at the extended position, then slowly (1-1.5 s) flexed the elbow to an unloading angle just below the starting position (elbow joint angle=75-80°). The weight lifted was equivalent to 10% of the subjects' pre-training isometric maximum voluntary contraction (MVC). Two warm-up sets were performed at ~ ¾-full speed for 6 repetitions before the maximal effort training sets. Training consisted of 5 sets of 6 repetitions with 20 s rest between repetitions and 2 min after each set. Training was considered ballistic since movement time was approximately of the same duration (~ 200 ms) as other studies employing ballistic movements (Desmedt & Godaux, 1979).

Subjects received motivation and instruction vocally and visually (worded pinups) during training and testing to improve performance (Bigland-Ritchie, 1978). Motivational phrases consisted of the words "explosive", "ballistic" and "maximal" to encourage a rapid maximal effort.

2.2.3 HEAVY RESISTANCE (HR) TRAINING

2.2.3.1 HEAVY RESISTANCE APPARATUS

The HR and one repetition maximum (1 RM) testing apparatus consisted of a single cable pulley system mounted to a wall, with one end of the cable attached to a weight stack and the other positioned superiorly across the subjects' training arm's shoulder, allowing a neutral grip by the subject of a 3/4 inch rope attached to the cable. The subject sat upright in a stationary chair with his elbow supported in the horizontal plane by adjustable table pads. Shoulder angles were identical to those of the subject seated in the ballistic apparatus. A load cell was attached between the cable and the weight stack by steel hooks during testing. Torque signals from the strain gauge were acquired and analyzed on the same system as the ballistic apparatus.

2.2.3.2 HEAVY RESISTANCE TRAINING

The HR arm did 5 sets of 5-7 repetitions with the greatest weight that could be lifted (~80-90% 1 RM). A rest period of 2-3 minutes was given between sets. Starting joint angles of the HR arm approximated that of the BL arm. Subjects performed a concentric elbow extension lasting approximately 2 s, and then returned (eccentric action) to the starting position in a slow (2-3 s) controlled manner. The weight lifted was increased once the subject could complete more than 7 repetitions and decreased if fewer than 5 repetitions could be performed in a set. Sets were taken to volitional failure except during the first 3 weeks when the mid- week training weight (intensity) was lowered to 90% of the last training day's weight to allow the subjects to become accustomed to training. Training intensity was also reduced the last 2 weeks of training to prepare subjects for testing. Before the 5 training sets, 2 warm-up sets were given with ½ and ¾ of the prescribed set 1 training weight.

2.2.4 TESTING & MEASUREMENTS

To minimize a learning effect from training and apprehension about electrical stimulation associated with measurement of contractile properties; all subjects were familiarized with the testing and training equipment on two separate occasions prior to pre-testing. Subjects were tested prior to training (pre-test), and after 17 weeks of training (post-test). Post-testing started 3 days after the last training session to allow the dissipation of any residual fatigue from training. The training group was tested in both arms while the control group (selection randomized) had only one arm tested. Subjects attended 5 different testing sessions, with evoked contractile properties, MVC, and ballistic actions of one arm being recorded in one session. Subjects were allotted 3-5 min. rest between these tests. All other tests were on separate days. The descending order of measurement in Figure 1 is the order of testing during the study. Testing sessions took place over a period of approximately 3 weeks both pre and post-training. To ensure validity and reliability of testing, both BL and HR testing equipment were calibrated prior to pre and post-testing.

2.2.4.1 BALLISTIC ACTIONS

Positioning the subject for ballistic action testing was identical to that for training. Prior to the performance of the ballistic actions, the forearm brace was locked at 90° to set the torque baseline, and then released to a unloaded position ~ 85 - 89°. The subjects brought the fully supinated forearm to a stationary position just prior to the generation of torque through lifting of the load, ~ 90°, paused a moment, then "explosively" extended the elbow through a 85°arc, driving the medial portion of the hand into a cushioned pad. Subjects attempted to hold the arm in this position momentarily to prevent an uncontrolled return to the starting position. Subjects were instructed to not move any other body part in an effort to assist elbow extension.

Testing was done with a load equal to 10% of the subject's pre-training MVC. The 10% load was chosen for several reasons: 1) values for movement time were similar to other research studies; 2) subjects were able to attain high peak torque and velocity not possible with other loads; 3) and similar loads are used in various athletic training programs. The 10% pre-training load was used during all ballistic training sessions throughout the study, and for the ballistic post-training testing session to determine how effective this training would be on the initial testing session load. It is common for many athletes in explosive athletic events to encounter the same scenario, since the load to overcome is often standardized (shot put) or undergoes very little fluctuations (sprinting). The isometric MVC was used as a reference to set the ballistic load for testing and training. It was also not considered necessary to make adjustments following training as previous research (Bauer & Sale, unpublished) has demonstrated the ineffectiveness of ballistic training to alter isometric MVCs after ballistic training using the same apparatus and daily volume (repetitions x sets) as the current study. Six (10% load) submaximal efforts where given prior to each maximal testing load to provide a warm-up, since improvement may occur after the first few attempts at high velocities (Sale, 1991). Testing consisted of five voluntary maximal ballistic elbow extensions with 2 min rest between actions. The ballistic action producing the highest peak torque (PT) was analyzed for PT, time to peak torque (TPT), movement time (MT), peak rate of torque development (RTD), peak velocity, peak acceleration, and peak power (Fig. 4). The peak torque value was used , similar to the 1 RM and MVC measures. The window for analysis started at the onset of agonist EMG activity and ended when peak torque reached a value of zero. This was approximately the point where the subjects hand made contact with the striking pad (Fig. 4). Peak RTD was attained from the smoothed (10 point moving average) and differentiated torque signal. Displacement recordings were smoothed (30 point moving average) and differentiated to give peak velocity. The velocity signal was again filtered (30 point moving average) and differentiated to give peak acceleration. Peak power was attained through the multiplication of the velocity and torque signals.

2.2.4.2 MAXIMUM ISOMETRIC STRENGTH

Isometric maximum voluntary contractions (MVC) of the triceps brachii were performed in the ballistic arm manipulandum to determine the ballistic movement preload of 10% MVC. Prior to recording, two brief submaximal elbow extensions were performed to set the EMG recording amplification, provide warm-up, and increase reliability. Subjects were instructed to develop maximal force as fast as possible ("hard & fast"), as it has been demonstrated that the both MVC and maximum RFD are maximized with this instruction (Bemben et al., 1990). Two elbow extension triceps isometric MVCs were recorded with 3 min. rest periods between efforts. The largest MVC was selected for determination of the ballistic testing and training loads, as well as analysis. Analysis consisted of PT, TPT, average RTD (ARTD = PT/TPT), and peak RTD. Torque recordings were smoothed (10 point moving average) and differentiated to allow peak RTD to be attained from the resulting profile.

2.2.4.3 ONE REPETITION MAXIMUM (1 RM)

Prior to the testing, 2 warm-up sets were performed on the ballistic apparatus with loads equal to 35% and 55% of MVC. Testing began with a starting load of 75% of MVC and was increased 2.5-5% until failure. Rest between 1 RM attempts was 2-3 min. In a couple of instances the 75% load caused failure and the weight was then reduced by 5-10%. The subject's maximum was usually reached in less than 5 trials. The final (maximal weight lifted) 1 RM was analyzed for peak torque.

2.2.4.4 ELECTROMYOGRAPHY (EMG)

Prior to the bipolar configuration placement of 5 EMG (2 triceps, 2 biceps, 1 ground) electrodes (3M Red Dot ECG pediatric electrodes), the skin over triceps and biceps was prepared by shaving, abrading, and wiping with alcohol. Stigmatic and reference electrodes were placed ~2.5 cm apart ~16 cm proximal to the olecranon covering the proximal portions of the lateral and long heads of the triceps brachii, and over the biceps brachii muscle belly. The ground electrode was placed half way along the ventral portion of the forearm. The EMG electrodes recorded agonist activation and antagonist coactivation during MVCs, ballistic elbow actions, and 1 RMs. Amplified EMG signals were fed through a low frequency (10 Hz) band-pass filter and then a high frequency (3 kHz) band-pass filter and amplified before delivery through a 12 bit A/D converter (Dataq Electronics), and recorded by a microcomputer sampling at 1495 Hz/channel and operating CODAS data acquisition software (Dataq Electronics).

Electrode placement was measured, marked, and recorded for similar post-testing positioning.

During analysis raw EMG recordings were full wave rectified (FWR), smoothed using a 25 point moving average function, and integrated (IEMG) for both the elbow flexors and extensors. Average EMG (AEMG) was obtained by dividing the IEMG by the duration of agonist and antagonist activation. The ballistic activation duration was taken as the time from onset of EMG to when torque equaled zero (~ 175° of extension). An EMG window starting with the onset of activation and lasting 2 s was used for analysis of the MVC data. The 1 RM EMG analysis window started at the onset of activation and stopped at the end of the concentric phase of the movement (maximal elbow extension). A subject's torque and raw EMG of agonist (extensors) and antagonist (flexors) are shown in Figure 5 demonstrating the large differences between the two training modes.

2.2.4.5 EVOKED ISOMETRIC CONTRACTILE PROPERTIES

Before the study, subjects were habituated to the electrical stimulation, as our laboratory has found this initial experience provides more reproducible twitch measurements during successive stimuli. The skin of the triceps and biceps brachii was prepared as described above for the EMG recordings before placement of the stimulating electrodes. Two lead surface electrodes wrapped with gauze and coated with conducting gel were taped to the elbow extensor muscles and tendon. The cathode (80 mm x 40 mm) electrode was placed laterally approximately 18 cm proximal to the olecranon covering the proximal portion of the lateral and long heads of the triceps brachii. The smaller anode (55 mm x 40 mm) was also positioned laterally 6 cm proximal to the olecranon across the triceps brachii tendon.

The subject's supinated forearm was strapped into the ballistic apparatus brace with the elbow joint at 60° of flexion (180° = full extension). The upper arm was supported in the horizontal plane at a shoulder joint angle of 90°. This joint position placed the triceps muscle on stretch, thereby maximizing the twitch response (Rice et al. 1992).

A series of single stimuli (30-300 V) was delivered with a rectangular pulse width of 100 μs by a high voltage stimulator (Model S11 Grass instruments) coupled to an isolating transformer (custom-made). Voltage was increased with successive stimuli until peak torque (PT) was attained. Twitch PT was established when less than a 5% increase in torque between two successive voltage changes occurred. Stimulus was increased 10% above the voltage providing the maximal twitch to insure maximal activation of the muscle (Edwards et al. 1977). Biceps stimulation was avoided by placement of the electrodes, as was determined by palpation, visual observation and EMG. It has also been shown in our laboratory that at this extreme joint angle very little force is produced when the biceps was stimulated directly (unpublished observation). Once twitch PT was established, 5 successive twitch responses were recorded with at least 30 s between each stimuli. The twitch with the highest PT was analyzed on a custom-made computer program (Oleksuik, McMaster University). Measurements included *peak torque* (PT), *time to peak torque* (TPT) defined as starting at 2% of PT and ending at 100% (2%-100% of PT), *rise time* (RT) (10%-90% of PT), *maximum rate of torque development* (MRTD), *maximum rate of torque relaxation* (MRTR), *half relaxation time* ($^1/2$ RT), and the sum of TPT and $^1/2$ RT. The total torque-time integral (2% ascent to 2% descent) was also measured from the torque trace. See Figures 6 & 7 for visual depiction of these measurements.

2.2.4.6 BODY COMPOSITION ANALYSIS

Body composition (bone, fat, and lean tissue mass) was measured by dual-energy x-ray absorptiometry (DPX) on a Hologic 1000-W Densitometer (Waltham, MA) located in the Nuclear Medicine Department at Chedoke-McMaster Hospital. DPX data on 2 control subjects was not analyzed because of damaged data files. Whole-body scans allowed determination of whole-body fat and lean body mass. Limb and trunk segmental analysis was incorporated into the whole-body scan (Fig. 8). Additional regional analysis was performed by using alternative software functions so upper arm lean mass could be determined (Fig. 9). Subjects were positioned in approximately the same location pre and post-testing so regions of interest would be more reproducible.

Following post-testing, analysis was performed without knowledge of the subjects being tested by a skilled colleague and one of the investigators so post-testing whole body scan subregions could be compared to the pre-testing scans. Depicted in Figure 8 (whole body) and 9 (regional arm) are two different training subject's pre and post-training DPX analysis scans.

2.2.4.7 MUSCLE BIOPSIES & HISTOCHEMISTRY

A percutaneous needle biopsy (Bergström, 1962) with suction was used to extract large ~80-140 mg muscle samples from the long head of the triceps brachii. An attempt was made to take the post-training biopsies at approximately the same location (~1.0 cm lateral to pre-training biopsy scar) of the pre-training biopsy. Samples were mounted cross-sectionally in an embedding medium (Histo prep), immediately frozen in isopentane cooled by liquid nitrogen to -159° C, and stored in a freezer at ~25° C until analysis.

Muscle samples were thawed to -20° C and serially sectioned (12 µm thick) in a cryostat for histochemical staining. Sectioned muscle was stained for myofibrillar adenosine triphosphatase (mATPase) activity after preincubation at pH values of 4.3, 4.6, and 10.2 (Brooke & Kaiser, 1970), using Brooke's and Kaiser's 1970 technique, with modifications by Staron et al. (1983). For explanation of staining intensities due to stability and lability at different preincubation pH levels, see Staron and Hikida (1992). Slides of each sample incubated at a preincubation of pH 4.6 were photographed under a light microscope (X10 magnification lens) using a 35mm camera. Along with the projected film, slides incubated at pH 4.3 and 10.0 were used to classify fibers as type I, IIa, IIab, or IIb and determine the total number of fibers/sample. The mean number of fibers per fiber type is shown in Table 2. Due to the low count and percentage of Ic, IIc, and IIac fibers present in the samples, these fibers were divided into their appropriate primary fiber types. A small biopsy sample size in one pre-training arm of 5 subject's resulted in the use of the other arm's pre-training values to determine fiber type and fiber area measurements. A small biopsy sample size in the control subjects also resulted in the use of only 6 subjects for fiber type and area measurements. A mean of at least 70 fibers for each major fiber type (I, IIa, and IIb) was measured using a direct tracing (200x magnification)and digitizing tablet for determination of fiber cross-sectional area (CSA). Because of a small sample size in two subjects, the number of fibers measured for CSA was as low as thirty-five. Due to the low numbers of IIb fibers post training, IIab fibers were included with IIb fibers for CSA measurements when necessary. Longitudinally sectioned fibers were not used for analysis. All fiber analysis was conducted with the investigator blind to the identity of the sample.

2.2.4.8 STATISTICAL ANALYSIS

Descriptive statistics included mean ± standard deviation (SD) or standard error (SE) for all dependent measures. Control subjects' data were statistically analyzed to determine reproducibility of testing measures over the period of the study. A one way within subject analysis of variance (ANOVA) was used to determine significant differences in control subjects' dependent variables before and after the training period. Method errors (ME) were also calculated for the testing measures. Method error was determined by dividing the square root of the between test variance (mean square error) by the mean of the within subject group mean values and multiplied by 100 to give a percentage value (Chilibeck et al., 1994).

A 2 factor within subject repeated measures analysis of variance (ANOVA) (2 [training modes] x 2 [times]) was used to determine the effects of training on the dependent variables. A Tukey post hoc test analysis determined significant differences between means when significant interactions were found (mode x time). Level of significance was set at $P \leq 0.05$, but if this criterion was fulfilled, $P \leq 0.01$ and $P \leq 0.001$ were also used. Where percentage increases in various measurements are stated in the text and tables, the formula (post-mean — pre-mean)/pre-mean x 100 was used.. Statistical analysis was conducted using Statistica (STATSOFT) for Windows and CLR ANOVA (Macintosh) computer software.

2.3 RESULTS

Subjects' anthropometric measurements are presented in Table 1. Due to an injury in one of the training subjects, all data analysis for the training subjects was performed on the remaining 9 subjects. The control subjects % body fat was higher pre and post-training compared to the training group. Subjects were randomly assigned to either a control or training group, but because 2 subjects decided not to participate after being selected to the control group, the next 2 subjects that applied to participate took their place. This should not have caused such a difference as all other subjects were randomly placed into the groups. The difference observed in pre-training type I and IIb fiber composition between the control and trained subjects is also unexplainable.

2.3.1 CONTROL SUBJECT REPRODUCIBILITY

Ballistic peak acceleration was found to be significantly ($p=0.02$) different in the control group after 17 weeks. Peak acceleration decreased from 124.1±15.0 to 116.5± 16.9 rad·s^{-2} (-5.7%). All other measurements were considered reproducible (data not shown). Method errors were calculated to provide information about the test-retest reproducibility (Appendix C).

2.3.2 BALLISTIC PERFORMANCE

No significant mode x time interactions were observed in any of the ballistic performance measurements, indicating that the training response was the same for both HR and BL after 17 weeks of training. However, significant overall increases (main effects for time) in peak torque, peak velocity, and peak power occurred, whereas movement time decreased. Peak acceleration, peak RTD, and TPT did not change significantly. The results for ballistic performance are presented in Table 3.

2.3.3 MAXIMUM VOLUNTARY CONTRACTION (MVC)

The results for isometric performance are shown in Table 4. Peak torque increased 1.5% and 15% in the BL and HR arms respectively (significant mode x time interaction). There were no significant changes in the time-related measures.

2.3.4 ONE REPETITION MAXIMUM (1 RM)

One repetition maximum (1 RM) increased 33.1% in the HR arm, but did not change significantly in the BL arm (0.2%, mode x time interaction, Table 4)

2.3.5 ELECTROMYOGRAPHY

The results for ballistic, MVC, and 1 RM agonist EMG are presented in Table 5, antagonist EMG in Table 6, and antagonist/agonist coactivation in Table 7. Ratios of Ball/MVC, Ball/1 RM, and 1 RM/MVC are presented in the above tables for each EMG variable.

2.3.5.1 AGONIST EMG

The results for agonist (triceps) EMG are shown in Table 5. There were significant overall (main effects) increases in AEMG in the ballistic action and isometric strength tests. As indicated in the table, the increases were much larger in the HR arm; nevertheless, there were no mode x time interactions. In the weightlifting 1 RM test, the greater increase (23.8 vs. 1.1%) in the HR arm was associated with a mode x time interaction.

To assess whether AEMG changes were specific to particular tests (ballistic vs. isometric vs. 1 RM), agonist EMG ratios were calculated: ballistic/MVC, ballistic/1 RM and 1 RM/MVC. There was no significant changes in these ratios (Table 5).

2.3.5.2 ANTAGONIST EMG

The results for antagonist (biceps) EMG are shown in Table 6. There were no significant changes in the ballistic action, isometric (MVC), and 1 RM tests, however, the antagonist ballistic/MVC ratio increased more in the BL (49.3%) than HR (8.6%) arm (mode x time interaction). The 1 RM/MVC ratio increased similarly in the BL (19.7%) and HR (23.6%) arms (time main effect). The ballistic/1 RM ratios did not change significantly, but showed the same pattern of results as the 1 RM/MVC ratio.

2.3.5.3 ANTAGONIST/AGONIST COACTIVATION

To assess whether changes in muscle activation differed in agonist (triceps) or antagonist (biceps) muscles, antagonist/agonist coactivation ratios were calculated, and are shown in Table 7. In the ballistic action test, the coactivation ratio increased (23.4%) after BL training but decreased (-22.7%) after HR training (mode x time interaction). In the isometric (MVC) test, BL (-23.4%) and HR (-23.6%) arms showed similar decreases in the ratio (time main effect). There were no significant changes in the 1 RM test.

To assess whether changes in coactivation were specific to a particular test, ratios were calculated similar to those for agonist and antagonist EMG. The ratios are shown in Table 7. The ballistic/MVC ratio increased more with BL (64.5%) than HR (9.0%) training (mode x time interaction). In the ballistic/1 RM ratio, the BL arm increased (28.9%) and the HR arm decreased (-16.7%), but there was no mode x time interaction. The 1 RM/MVC ratio increased similarly after BL (30.1%) and HR (23.1%) training (time main effect).

2.3.6 EVOKED CONTRACTILE PROPERTIES

The results for evoked contractile properties are shown in Table 8. Peak torque increased 1.5% and 15% in the BL and HR arms respectively (significant mode x time interaction). A similar changed occurred in the TTI with the HR arm increasing much more than the BL arm. There were no significant changes in TPT, RT, MRTD, MRTR, TTI, ARTD, or ½ RT. However, both ARTD (p=.065) and ½ RT (p=.073) did show trends towards significant changes (main effects for time). The HR and BL increased by 26.0% and 6.6 % in ARTD; and 10.6% and 0.6 % in ½ RT respectively. The twitch/MVC ratio did not change significantly following training.

2.3.7 MUSCLE FIBERS

2.3.7.1 HISTOCHEMICAL FIBER TYPE

Following training, no significant differences were found in type I or type IIab fiber percentage. Type IIa and IIb fiber type percentage showed a significant ($p \leq 0.05$) mode x time interaction following training. The percentage of type IIb fibers decreased in the HR arm by -62.3% while a concomitant increase in the percentage of type IIa fibers by 37.8% was observed following training. Post hoc analysis revealed no significant change in the BL arm in either fiber type following training. A significant ($p \leq 0.01$) main effect for time was also observed in type IIb fiber percentage (Table 2).

2.3.7.2 FIBER CROSS-SECTIONAL AREA

The results of fiber CSA measurements are shown in Table 9. Type I fibers were 81% of type IIa and IIb fiber areas prior to training and 72-76% after training.. All 3 fiber types showed a significant ($p \leq 0.005$) mode x time interaction following training. Type I, IIa, and IIb fiber CSA increased in the HR arm by 28.0%, 43.0%, and 41.4%, respectively following training. In contrast, the BL arm had modest changes in the 3 fiber types of -4.7%, 8.3%, and 3.0%, respectively after training. A significant ($p \leq 0.05$) main effect for time was also observed in type IIa and IIb fibers areas.

2.3.8 ANTHROPOMETRIC MEASUREMENTS

There were no significant differences between the control and training group in age, height, body mass, or lean body mass. There was, however, a significant difference ($p \leq 0.05$) between the two groups in body fat following training (Table 1). The training group percentage body fat had decreased (12.9±3 to 12.0±2.5 %), while the control group increased (14.9±4.4 to 15.6±4.1 %). A significant ($p \leq 0.005$) mode x time interaction was observed in DPX regional analysis (upper arm) of lean muscle mass. Post hoc analysis demonstrated that the HR increased significantly ($p \leq 0.001$) more than the BL arm. The HR and the BL arm increased from 1030.3±211.9 to 1149±301.1 g (11.6%) and 1030.5± 213.7 to 1040.8±239.1 g (1.0%) respectively, following training.

2.4 DISCUSSION

2.4.1 BALLISTIC, MVC, AND 1 RM PERFORMANCE ADAPTATIONS

A major finding was the absence of a high velocity specific training response; that is, heavy resistance (low velocity) training increased high velocity peak torque, peak velocity, peak power and MRTD to an extent similar(not significantly different) to that achieved by high velocity "ballistic" training (Table 3). This contrasts with many studies of concentric isovelociy (isokinetic) training actions, which demonstrate high velocity training specificity (Coyle et al., 1981; Ewing et al., 1990; Kaneshia & Miyashita, 1983). The HR training in the present study might have been expected to cause a marked high velocity training response if the subjects had intended to lift the heavy weight as quickly as possible, since it has been shown that the intent to make a ballistic action may be more important that the actual movement velocity for inducing a high velocity training response (Behm & Sale, 1993). However, in the present study there was no intent to lift the heavy weights quickly, yet high velocity performance improved. Other studies have shown similar results to the present with increased dynamic ballistic PT when HR loads between 70-100% 1 RM were used, (Dahl et al., 1992; Kaneko et al., 1983; Newton et al., 1995).

On the other hand, a low velocity specific training response occurred in that heavy resistance training produced the greatest increase in weight lifting (1 RM) and isometric (MVC) strength. This agrees with several previous studies (e.g. Häkkinen & Komi, 1985a; Wilson et al., 1993). The heavy resistance training may have increased 1 RM and MVC performance more because it produced greater increases in agonist EMG (neural adaptation), as well as isometric evoked contractile peak torque, and whole muscle and fiber size. It may be that the duration and force applied to the muscle were insufficient during BL training to increase maximal peak force during the 1 RM and MVC tests, as the mechanical tension generated by the muscle has been suggested to be the key factor in causing increased force (Atha, 1981). Even though we did equate the number of reps and sets in the present study, the overall time of tension development was vastly different with HR training lasting approximately ~ 4 s/rep, and ballistic tension lasting only ~.250 s/rep, or 1/16th of the time. Thus, besides the PT, velocity, acceleration, RTD, and power being quite different in the two modes of training, so too was the total time of contractile activity. One or a combination of these differences may have contributed to the low velocity specific training response. Figure 5 (showing ballistic 10% MVC and 85% 1 RM PT), demonstrate the much higher PT and longer duration of the concentric phase of the HR compared to the ballistic training action. The increase in ballistic PT found in the present study was similar to that of previous studies performed in this lab (Bauer et al., 1995).

The present study did not demonstrate any significant differences in isometric MRTD or ARTD; however, a trend for an increase in the BL arm and a decrease in the HR arm was observed (Table 4). Isometric RFD has been shown to increase with BL training (Häkkinen 1985b), but not HR training (Häkkinen et al., 1985a; Sleivert et al., 1994). Others have observed a larger percentage increase in RFD following BL training compared to HR training (Wilson et al., 1993). The trend observed in this and other studies may be attributed to the way the action is attempted; that is, a high RFD occurs naturally in BL but not HR training (Table 7). The attempt to make a ballistic movement has been said to be important in improving RFD, as Behm & Sale (1993) demonstrated a increase in isometric RFD after both ballistic isometric and isokinetic training. Another study also demonstrated a non-significant increase of 68.7% following explosive HR barbell squats but only a 23.5% increase following slow actions HR training (Young & Bilby, 1993). But in the present study, while the isometric test showed a trend towards a difference in RFD between the training conditions, dynamic ballistic maximum RFD did not significantly increase following training. However, both training programs produced an increase. In contrast, previous research using the same training apparatus in this lab has produced a significant increase (Bauer et al., 1994, 1995). It is unknown why the present study did not show similar results. Possible reasons could be the large method error (21.7%) associated with this testing measure, the lower number of subjects (9 vs. 16 which could result in decreased statistical power in this study), and/or the fact that the previous studies used a preloaded (load supported prior to muscle action) action. The preload pre-training MRTD values from the previous studies where lower, which may be due to the training status or possibly the difficulty in moving an object from a preloaded condition. Another possibility could be that the training strategy changed over time and as the purpose was to attain final peak power by driving through the punching bag, the initial MRFD which was observed early on in the movement may not have been as necessary. Further analysis of the data and study is needed to determine if this is a plausible explanation.

The present study is one of very few to show a significant increase in ballistic peak velocity following training (Bauer et al., 1995, Duchateau & Hainaut, 1984; Kaneko et al., 1983). When BL and HR training were used in combination, a 7.3% increase in peak velocity while performing jump squats with a 17 kg load was observed, but failed to reach significance (Newton et al., 1995). The testing load used in the current study remained constant pre to post-testing, but since the HR arm significantly increased MVC by 15%, the test load post-training was about 8.7% of the post-training MVC. The present laboratory has shown that PT and velocity are significantly ($p \leq 0.05$) different with loads of 10 and 5% of the MVC (Zehr et al., unpublished results). So it may be that the decreased percentage of the load relative to the MVC accounted for the changes seen in the HR training arm performance. This has also been seen previously with isometric training (Duchateau & Hainaut, 1984; Kaneko et al., 1983). The BL training arm did not affect the MVC PT, so other factors must have affected the improved velocity.

Peak power also increased following training, with a higher percentage increase (not significantly different) in the BL arm (Table 2). This result may not be surprising as BL (Duchateau & Hainaut, 1984; Kaneko et al., 1983), HR (Duchateau & Hainaut, 1984; Kaneko et al., 1983) as well as a combination of BL and HR training (Newton et al., 1995) has produced increases in power. But the largest gains in power have been produced with ballistic training. Kaneko et al. (1983), had subjects train with either 0% 30%, 60%, or 100% of their maximum force (Po). The largest gains in peak velocity were observed with 0% Po, while the 100% Po load increased Po to the greatest extent (Kaneko et al., 1983). The greatest gains in peak mechanical power have been reported to be seen following training using loads that are approximately 30% of Po (Kaneko et al., 1974 cited in Moritani 1992; Kaneko et al., 1983). It has been suggested that even higher loads with high speeds are what is needed to improve maximum power, even with weights up to 80% of the maximum (Bompa, 1990). As power is a key component in athletic performance, further research comparing different training load percentages is needed.

The non-specific ballistic performance response to both training modes has been suggested to occur with subjects who exhibit a low level of force and velocity prior to training (Komi & Häkkinen, 1988). However, the present training was carried out over 17 weeks, and as can be seen in (Fig. 2) both arms appear to level off and slightly decline, suggesting that they have reached more of a trained state or that they may be slightly over-trained. Others have also shown similar plateauing of performance at approximately 9-12 weeks of training (Häkkinen et al., 1988; Häkkinen & Keskinen, 1989).

The lower percent gain in ballistic peak torque (12.7%) over the heavy resistance 1 RM (31.3%) was expected, and observed previously (Narici et al., 1989; Newton et al., 1995). Part of the larger response by the HR arm could be due to motivation, as the kinesthetic feedback from ballistic movements as to the amount of force generated is less than during HR training (Perrine, 1986). Even with our subjects receiving visual feedback approximately every other week from a computer screen or oscilloscope, they still had difficulty in keeping motivated and being aware if one trial was better than another in peak torque production (author's observation). It may also be that the mechanism(s) responsible for increased ballistic performance are more difficult to activate than those for high resistance performance.

2.4.2 ELECTROMYOGRAPHY

Agonist EMG showed a specific effect for training in the 1 RM test, with the HR arm increasing more than the BL training arm. This adaptation to training has been observed previously following HR training (Häkkinen & Komi, 1983; Häkkinen & Komi, 1986; Häkkinen et al., 1985a; Moritani & Davies, 1979; Keen et al., 1994). It has been interpreted that an increase in EMG represents the ability of the subject to more fully activate the prime movers involved during a MVC following training (Sale, 1988). In contrast, other studies have not shown an increase in agonist EMG after HR training (Baker et al., 1994; Garfinkel & Cafarelli, 1992; Weir et al., 1995). The differences in activation of muscle by BL and HR training might suggest that after these unique training modes, differences in neural drive might be detected. An inhibitory feedback loop acting to reduce high force outputs during HR type actions may be present (Westing et al., 1988). An action-specific facilitory or inhibitory synaptic pathway acting to disinhibit higher brain centers or inhibit peripheral reflex tissue like Renshaw cells and Golgi tendon organs has been suggested to account for the increased agonist EMG (Narici et al., 1989). The ballistic arm did not increase in agonist EMG to account for the performance increases. This is similar to one study (Häkkinen & Komi, 1986), but in contrast to an explosive jump training study that did show increased agonist EMG (Häkkinen et al., 1985b). Research by Häkkinen and colleagues in 1985 found a correlation between increases in force and IEMG, even when the increase in IEMG was observed in isometric tests (Häkkinen et al., 1985a, 1985b). Also of interest was that at the onset of activation, EMG increased 38% more than peak EMG in the explosive jump training (Häkkinen, et al., 1985b), while weight training (Häkkinen, et al., 1985a) produced no increase in the onset of EMG compared to peak EMG, but displayed a small (3%) increase in the later portion of the activation. The adaptation caused by the "explosive" training may have been due to the high frequency burst pattern of motor units seen only during ballistic actions at the onset of the agonist burst, resulting from the higher firing rates (120 Hz) observed in ballistic actions (Sale, 1992). However, the study by Häkkinen et. al (1985b), also employed HR training concurrently with jump training on the same muscles groups, so changes that affected the group that only trained with HR might also have affected the jumping group.

The possible discrepancy between the HR arm in our study and those who did not produce an increase in agonist EMG could be the testing of non-training specific exercises (Baker et al., 1994), isometric vs. dynamic training (Garfinkel & Cafarelli, 1992) and testing of muscles that are not solely responsible for force production such as the many muscles that contribute to leg extension force (Weir et al., 1994,1995). Testing variability is also a possibility, as changes in muscle size and adipose tissue could affect the recorded EMG.

A loss or gain in adipose tissue thickness at the site of the electrode pick-up area would affect the amount of EMG signal recorded.. As the training was over 17 weeks and some body fat was lost (non-significant), it could have altered the EMG signal. Evidence for increased muscle size causing the observed increase in agonist EMG comes from the EMG ratios showing no change after training. If specific neural training adaptations occurred in the training arms during the different testing conditions, then the 1 RM/BL EMG ratio would have increased in the HR arm. Also, the regional limb mass and fiber areas increased after HR training but not in the ballistic arm, yet both improved in performance and only the HR arm increased in agonist EMG. However, an increase in muscle size alone should not affect EMG. Assuming the pickup area of the electrode remains constant, the same amount of muscle fiber membrane activity should be detected resulting in the same EMG, unless the muscle fiber packing density increased. However, there is no evidence to suggest this occurs.

A significant interaction in antagonist-agonist coactivation was observed with the BL trained arm increasing by 23.4 % and the HR arm decreasing by -22.7% in the ballistic testing. However, both arms decreased significantly in coactivation during the isometric

MVC. As isometric actions are restricted by their nature from movement, the need to stabilize and protect the joint might be less. A similar reduction in coactivation of the hamstring muscles was observed during a MVC knee extension following 8 weeks of knee extensor isometric MVC training (Carolan & Cafarelli, 1992). The unfamiliar act of the loaded single joint ballistic action ending by striking a bag, may account for the BL arms' increase in coactivation. Skill acquisition has been shown previously to increase the amount of coactivation during improved performance at speeds of 40 deg/s and 200 deg/s with movement times of 300 ms and 1500 ms (Engelhorn, 1983). However, even in skilled performance of olympic weightlifting, which has both a heavy resistance and ballistic (explosive) phase, some degree of antagonist coactivation is present throughout the entire movement (Enoka, 1983). But unlike olympic movements, the present HR training had no ballistic component and was done in a slow deliberate fashion. Also, in the BL trained arm, the increased coactivation during the ballistic action was brought about by an increase in antagonist activity, while the HR training induced a reduction in the coactivation, not by decreased antagonist but increased agonist activity. Therefore, the motor control pattern was different than that of a BL action. Increased coactivation has also been observed following heavy resistance training (2 wks) of the antagonist in a group of jumpers who previously had less coactivation than control subjects during isokinetic knee extensions (Barratta et al., 1988), whereas after training the coactivation was similar to the untrained controls. The increased coactivation may only be temporary during HR training to allow better control initially until the subject learns to control the movement more accurately, or, it may be only reduced in isometric MVCs.

The continued practice and improvement in ballistic performance also increased the impact of the hand into the striking bag, which may have made the high antagonist activation essential to protect the joint. Increased antagonist coactivation could enhance stiffness and stability of the joint, especially during high velocity and high load movements (Osternig et al 1986), deceleration of the limb (Marsden et al., 1983), and/or minimization of impact force during striking actions as might have occurred during the present study with the subjects halting movement by contact with a karate punching bag. In some cases the increased stiffness provided by antagonist coactivation has been suggested to possibly decrease the agonist effort needed for the performance of movements (Hasan, 1986).

The observed increase in antagonist activity may not produce a negative effect if activation in another muscle group acting on the elbow joint as an antagonist is reduced but not detected. The biceps brachii, brachialis and brachioradialis all act as antagonists, but since the electrode was placed primarily over the biceps brachii, changes in the other muscles may not have been detected. Another possibility is that EMG was averaged over the entire activation duration, and a triphasic pattern may have occurred where antagonist EMG increased at the beginning of movement, decreased during the middle, and then increased at the end. However, there was no visible alteration in raw EMG that would suggest such an occurrence (Fig. 5).

The spacial spread of electrical activity to recording electrodes on adjacent muscles, often referred to as cross-talk, may contaminate EMG results. However, when a near-maximal stimulation was elicited to the medial gastrocnemius, M-waves of only 6% of the gastrocnemius was produced by the soleus (Moritani et al., 1990). The much larger distance between the electrodes and muscles of the upper arm compared to the lower leg plantar flexors suggests that any cross-talk would be minimal. In fact the maximum effective electrode pickup has been shown to be no greater than 20 mm in the biceps and triceps brachii muscles (De la Barrera & Milner, 1994). Also, if such an effect was prominent it might be expected that the adaptations in EMG between training arms during the different testing conditions would be similar in direction and magnitude (Carolan & Cafarelli, 1992). This was not the case.

2.4.3 SKELETAL MUSCLE

2.4.3.1 EVOKED CONTRACTILE PROPERTIES

Training of similar duration to that performed by the HR arm has previously been shown to significantly increased isometric evoked PT as in the present study (Brown et al., 1990; Ramsay et al., 1990; Rice et al., 1993), whereas the ballistic training in this study failed to cause a change, in contrast to other BL training studies that demonstrated an increase (Bauer et al., 1995) or decrease (Duchateau & Hainaut, 1984). However, other BL (Behm & Sale, 1993) and HR (Alway et al., 1989; Alway et al., 1990; Kitai & Sale, 1989; McDonagh et al., 1983) training has not produced a change in twitch PT. It is possible that the type of training action (isometric) employed in the past HR training studies does not stimulate a change, or that the muscles trained (triceps surae, except McDonagh et al., 1983) are less adaptable. However, it is doubtful that the lack of muscle hypertrophy would be the cause, as studies have shown muscle (Sale et al., 1992) and fiber (Alway et al., 1990) hypertrophy with no change in twitch PT. If muscle size is at least partly correlated to twitch PT, and twitch PT related to the intrinsic force generating capacity of the muscle, then the change found in the present study may be a function of the larger muscle mass. The increase of 26.9% in the twitch PT can account for all of the 15% increase in MVC and most of the 31.3% increase in the 1 RM measurement in the HR arm. The failure of twitch PT to change after training in some studies has also been attributed to alterations in the extensibility of muscles, which would lead to a decreased ability for the transfer of the tension by the muscle to the series elastic component and external force production (Sale et al., 1982). The difference between the previous ballistic studies and the present is unclear, especially the previous training study performed in our lab, because the same apparatus and muscle groups were used (Bauer et al., 1995). It could be that specific alterations were caused by the preloaded condition used in our previous studies compared to the unloaded starting point in this study.

Torque-time integral (TTI) was significantly increased after training in the heavy resistance arm, which could be partially due to the increase in twitch PT. It may also be possible that the increased TTI is related to a increased contraction time, since although no other evoked contractile properties changed significantly, ½ RT did approach a significant increase following training. The increase in ½ RT would prolong the twitch resulting in a larger TTI. Other studies have produced mixed results in CT (TPT), with ballistic (Bauer et al., 1995) and heavy resistance (Brown et al., 1990; Duchateau & Hainaut, 1984; Keen et al., 1994; McDonagh et al., 1983; Ramsay et al., 1990) training causing no change, a decrease in ballistic (Behm & Sale, 1993; Duchateau & Hainaut, 1984) and heavy resistance (Alway et al., 1989; Alway et al., 1990), or a increase in heavy resistance training (Rice et al., 1993). A similar mixed result has also been observed following both ballistic and heavy resistance training in ½ RT in the above mentioned studies. The discrepancy between the study by Duchateau & Hainaut (1984), which produced a decrease in twitch CT, ½ RT, PT and increased MRFD with isotonic ballistic contraction training after 3 months, could be due to the ~7.7 fold greater number of ballistic actions performed in that study with a 10-20% greater load than the present study. The ballistic training in the present study did not affect MRFD like others (Behm & Sale, 1993), but again possibly due to the initial loading condition did not increase RFD as shown by our previous study (Bauer et al., 1995).

The discrepancy observed in twitch evoked contractile properties could be the large variability observed in measurements in the control group. The elbow joint angle used in recording the twitches may not have been small enough to take up all the series elastic component, which may affect the twitch recordings. A better indicator of the intrinsic capacity of muscle is believed to be tetanus peak force (Sale et al., 1992). However, tetanic stimulation of the elbow extensors was found to be unbearably painful for the subjects. Although technically challenging, single fiber analysis of Vmax and peak tension could provide insight into the speed of contraction and force producing ability of the muscle. But as yet only one non-ballistic study on human swim sprint training has been published (Fitts et al., 1989).

2.4.3.2 FIBER TYPE COMPOSITION

The finding of a shift in fiber type composition from IIb→IIa in the HR arm is similar to that found by others (Adams et al., 1993; Colliander & Tesch, 1990; Hather et al., 1991; Staron et al., 1989; Wang et al., 1993). This alteration towards a more oxidative fiber maybe thought to be detrimental to those activities requiring high power outputs and velocity, but could produce benefits like a decrease in fatigue and a increase in training volume. In contrast, to sprint cycling, which has shown an increase in the type II fiber composition, decreased type I fibers (Jansson et al., 1990; Esbornsson, et al., 1993), or the same shift observed as found in HR training (Allemeier, et al., 1994), the present BL training did not alter fiber type composition. So although BL training may (Grimby & Hannerz, 1977) or may not cause selective activation of fast twitch motor units and have higher brief firing rates than slow continuous movements (HR training) (Desmedt & Godaux, 1979), it does not appear from the present study that a conversion occurs to increase the speed of contraction of the muscle. However, the triceps muscle group already possesses a high percentage of IIb fibers, which may make a further increase more difficult compared to other muscle groups that have a lower percentage such as the vastus lateralis (Jansson et al., 1990). Also the high method error using histochemical analysis to detect IIb fibers, could have left a change undetected. However, it might not be necessary or possible to significantly shift the muscle fibers from type I→II, or even alter subtypes to a faster fiber (IIa→IIb) using typical training practices. Furthermore, changes in excitation-contraction coupling (Alway et al., 1989, Alway et al., 1990) and fiber Vmax (Fitts et al., 1989) may also affect muscle contractile speed without a change in the fiber type.

2.4.3.3 FIBER AREA

A highly specific increase in fiber area was observed only after HR training, and it has been well documented that such training commonly increases fiber area (Coyle et al., 1981; Häkkinen et al, 1985a; MacDougall, et al., 1979, 1980; McDonagh & Davies, 1984; Staron et al., 1989). Type II fiber area increased 14% more than type I. A greater type II fiber hypertrophy after HR training has been observed previously (Alway, et al., 1989; Coyle et al., 1981; Häkkinen et al., 1985a; MacDougall, et al., 1979, 1980; Staron et al., 1989; Tesch et al., 1987), but others have not observed large differences in hypertrophy following heavy resistance training (Frontera et al., 1988; Tesch and Larsson, 1982). No increase in fiber area may occur due to the type of action (isokinetic concentric only) (Costill et al., 1979) or short training periods used (Costill et al., 1979; Staron et al., 1994). Greater hypertrophy of type II fibers may occur following training because of the increased use of these fibers compared to the normal amount they are recruited during daily activity (MacDougall 1992).

Ballistic training did not elicit significant fiber hypertrophy despite their probable recruitment and stimulation at high frequencies. Perhaps even though the intensity is high, the actions do not last long enough to stimulate increased net protein synthesis. In fact, only one study has shown fiber area increase with high velocity training (Dahl et al., 1992), while most have not (Allemeier et al., 1994; Jacobs et al., 1987; Thorstensson et al., 1975). Even though the intensity might have been high, the duration of fiber activation was low compared to the HR trained arm. The fact that the pre-training type I fibers were 19% smaller than the type II in the present study, has been found elsewhere, but the difference was much larger, with the type I fibers possessing only 60% of the type II area in triceps muscle (MacDougall et al., 1980). It must be remembered that muscle biopsies sample only a small amount of the muscle, and individual group variations may account for the difference between the two studies.

2.4.3.4 LEAN TISSUE MASS

The current training program demonstrated an increase of 11.6 % in the HR trained arm and 1.0% in the BL arm. Other HR training studies have reported fat-free mass changes of 6.2% and 9.6% after combined elbow flexor and extensor training was conducted for 16 (Treuth et al., 1994) and 20 (Calder et al., 1993) weeks, respectively. Increased muscle CSA is highly correlated with increased muscle fiber areas (McDonagh & Davies, 1984). Muscle CSA is primarily determined by the number and size of its fibers, with minimal contribution from connective tissue (MacDougall, 1992). Although only three studies to the author's knowledge have used the dual x-ray absorpitometry for analyzing increases in fat free mass of the arm following heavy resistance training, its reproducibility (Calder et al., 1993; Treuth et al., 1994) and correspondence to other sensitive measurements of CSA (MRI) following training have been demonstrated (Treuth et al., 1994). It is not then surprising that only the HR trained arm increased in lean mass, as it was the only arm to increase in fiber area. Also, twitch PT, which may represent increased force capacity of the muscle, increased only in the HR arm. Further evidence for only HR training increasing muscle mass has been demonstrated in cats under going HR training. A high negative correlation between lifting speed and muscle mass was found, with the slower the weight lifted (i.e. the heavier the weight), the greater the increase in muscle mass (Mikesky et al., 1991).

2.4.4 POSSIBLE EXPLANATIONS FOR BALLISTIC PERFORMANCE ENHANCEMENT

The increases in performance by the BL arm with no significant change in any of the tested measures leaves the question of the cause of the change still open. In fact, only a non-detrimental increase in antagonist coactivation of the flexors was discovered. Some of the possibilities that could explain the increases in the ballistic performance could have either gone undetected, or were not analyzed. The possibilities include: 1) increased specific tension, 2) increased fiber Vmax, 3) changes in muscle architecture (new connective tissue attachments, and increased pennation), 4) increased amount of connective tissue (changing elasticity), 5) either or both intra (within the same muscle) and inter-muscular (different muscle groups) coordination, and 6) increased motor unit firing rates, reflex potentiation, and/or synchronization. Increased specific tension as a result of increased myofibril packing density (Jones et al., 1989), is not well established (MacDougall et al., 1986). Also, human single fiber analysis showed no difference in or between type II and type I fibers' specific tension, while alterations in fiber Vmax did occur (Fitts et al., 1989). New attachments of connective tissue along the fiber have been postulated as a mechanism that could increase the specific tension of a muscle (Jones et al., 1989), but as yet this hypothesis is unproven. Although pennation angle may increase with muscle hypertrophy, there was no change in muscle mass. Although there was no change in muscle mass, and the addition of connective tissue has been shown to be proportional to increased muscle mass (MacDougall et al., 1983), it still maybe possible to solely develop new amounts of connective tissue. If there was new amounts and attachments of connective tissue and fiber pennation did occur following ballistic training, then the force generated by the muscle would be greater without a change in muscle size. However, evoked twitch torque and twitch time measurements would have been expected to change, but did not.

A within-subject control design with one arm HR-trained and the other BL-trained was used in the present study to alleviate inter-subject variations due to two groups training with different regimens. A concern often associated with such a design is the confounding effect of what is termed the "cross-training" phenomenon. The cross-training effect occurs when the adaptations in performance that occur in the trained limb are witnessed in the contralateral untrained limb. These effects are often considered neural adaptations (Houston et al., 1983). A superior performance by one arm than may bestow its gains upon the contralateral arm that received the inferior training regime. However, if the cross training effect did occur it would have provided a more stringent comparison between the two training programs, but a superior training mode would still have predominated. Evidence against the occurrence of cross-training in the present study was demonstrated in the much superior performance by the HR trained arm (mode x time interaction) observed during the 1 RM and MVC test, and the corresponding changes in agonist EMG and skeletal muscle size, as they were found exclusively in this arm. The non-training specific response seen in ballistic testing; further demonstrated the absence of a cross-over effect, as it seems reasonable to conclude that ballistic performance increased in the HR-trained arm due to the drop in the relative ballistic load tested (10% to 8.7%). Additional support comes from previous between subject training research that has shown improved ballistic performance following HR training (Duchateau & Hainaut, 1984; Kaneko et al., 1983; Voigt & Klausen, 1990).

2.4.5 CONCLUSIONS

The most important finding of this study was that there were no training specific improvements in ballistic performance, but heavy resistance training specifically increased isometric and low velocity concentric strength. Related to the latter, heavy resistance training also increased evoked twitch peak torque, whole muscle and muscle fiber size, and agonist EMG, while ballistic training did not produce these changes. Although it might be expected to be detrimental, the fiber conversion from type IIb to IIa did not produce a detriment in movement speed.

Although ballistic training improved ballistic performance, unlike heavy resistance training there was no transfer to MVC or 1 RM tests. The training-induced improvements in ballistic performance occurred in the absence of improved evoked twitch contractile properties, agonist muscle activation or a shift to a faster fiber type. In fact the only related change was an increase in antagonist coactivation in the performance of ballistic actions, which might be considered detrimental; however, it was not. The question then remains open as to what caused the improvement in ballistic performance following ballistic training.

As there is still very little research on ballistic training, additional research is needed. The next step might examine the combined effects of both ballistic and heavy resistance training, the effect loaded training has on unloaded rapid movement, the training load (% of MVC) that improves performance the most, and the effect of such training on other single joint movements. To enhance the detection of these changes, more sensitive measurement techniques such as single fiber Vmax need to be used. Also future developments in EMG will hopefully allow more precise assessment of muscle and motor unit activation in ballistic actions, since ballistic performance may be enhanced due primarily to these changes.

Table 1. Anthropometric measurements

Group	Body Mass, (kg)	Lean body mass, (kg)	% Body fat
Control (n=8)			
pre	76.2 ± 10.0	61.8 ± 6.7	14.9 ± 4.4
post	76.5 ± 9.1	61.5 ± 6.1	15.6 ± 4.1
Training (n=9)			
pre	73.8 ± 8.3	61.2 ± 6.1	12.9 ± 3.0 *
post	74.5 ± 83	62.6 ± 5.9	12.0 ± 2.5 *

Number of subjects (n=). Values are means ± SD. Significantly different than the control group pre and post-training * ($p \leq 0.05$)

Table 2. Control (N=6) and training (N=9) subject's fiber type distribution (%)

Group		n	Type I	Type IIa	Type IIab	Type IIb
CONTROL						
	pre	1095±948	36.8±5.5	31.3±8	12.6±5.7	19.1±8.2
	post	913±568	35.3±7.1	27.4±8.7	11.7±5.9	25.6±9.7
TRAINING						
Heavy resistance						
	pre	656±257	27.5±9.4 ‡	29.9±11.0	12.6±5.5	30.0±9.8 ‡
	post	736±259	28.9±12.2	41.2±9.3 *†	18.5±7.8	11.3±8.8 **†
Ballistic						
	pre	710±350	28.6±9.5	28.8±7.0	12.0±5.1	30.7±7.2 ‡
	post	1086±672	32.3±9.3	27.2±8.2	12.8±4.5	27.6±9.7

Fiber type values are means ± SD expressed as a percentage; n, is equal to the mean number of fibers per biopsy. Number of subjects (N=). Significantly different from pre-training value * ($p \leq 0.05$). Significantly different from pre-training ** ($p \leq 0.01$). Significantly different from the ballistic trained arm post-training † ($p \leq 0.05$). Significantly different from pre-training control ‡ ($p \leq 0.05$). A small biopsy sample size in one pre-training arm of 5 subject's resulted in the use of the other arm's pre-training values to determine fiber type.

Table 3. Ballistic performance

Measurements	Ballistic Training Arm			Heavy Resistance Training Arm		
	Pre-training	Post-training	Difference	Pre-training	Post-training	Difference
Peak Torque (N·m) *	21.3±1.7	24.0±3.8	12.7%	21.6±2.6	24.1±4.0	11.5%
TPT (ms)	98.8±27.8	101.1±16.4	2.3%	113.2±27.9	93.6±18.6	-17.3%
MRTD (N·m·s^{-1})	547.8±104.8	630.1±213.8	15%	498.7±125.5	582.8±115.6	16.7%
Peak Power (W) **	162.9±20.1	211.3±38.5	29.7%	163.5±24.2	196.3±39.2	19.8%
Movement time (ms) *	203.3±15.3	197.0±8.9	-3.1%	211.3±11.3	198.8±19.1	-5.9%
Peak Velocity (rad·s^{-1}) **	12.6±0.5	13.9±1.3	10.5%	12.6±0.8	13.6±1.3	8.1%
Peak Acceleration (rad·s^{-2})	126.9±10.0	131.9±18.0	3.9%	121.3±9.1	132.7±21.1	9.4%

Values are mean ± SD, and % difference. Significant main effect for time collapsed across groups (post vs. pre-training) values * $p \leq 0.05$, ** $p \leq 0.01$.

Table 4. Isometric MVC & 1 RM

Measurements	Ballistic Training Arm			Heavy Resistance Training Arm		
	Pre-training	Post-training	Difference	Pre-training	Post-training	Difference
MVC						
Peak Torque (N·m)**	53.1±9.0	53.9±7.7	1.5%	54.1±9.0	62.2±8.7 †	15.0%
TPT (s)	1.1±0.5	0.94±0.6	-14.5%	1.2±0.5	1.4±0.4	16.7%
MRTD (N·m·s^{-1})	534.5±164.3	624.9±107.4	17.0%	590.6±138.0	559.2±216.0	-5.3%
Time to MRTD (ms)	67.2±23.0	105.2±28.6	56.5%	80.0±67.5	103.7±28.0	29.6%
ARTD (N·m·s^{-1})	54.7±23.2	80.4±47.1	47.0%	74.8±93.7	47.5±15.3	-36.5%
1 RM						
Peak Torque (N·m)***	50.6±12.0	50.5±8.6	-0.2%	50.4±10.2	66.2±8.4 ‡	31.3%
Mass lifted (kg)***	13.5±2.8	13.9±2.4	3.0%	13.8±2.6	18.8±2.4 ‡	36.2%

Values are mean ± SD, and % difference. ARTD = Average rate of torque development, significantly different from ballistic training arm and heavy resistance pre-training † $p \leq 0.01$, ‡ $p \leq 0.001$. Significant main effect for time collapsed across groups (post- vs. pre-training values) ** $p \leq 0.01$, *** $p \leq 0.001$.

Table 5. Agonist electromyography (mV)

Measurements	Ballistic Training Arm			Heavy Resistance Training Arm		
	Pre-training	Post-training	Difference	Pre-training	Post-training	Difference
Ballistic action *	.6199±.1993	.6172±.1647	-0.4%	.6144±.1296	.7668±.1542	24.8%
MVC **	.7135±.2861	.7604±.1563	6.6%	.6597±.1635	.8357±.1743	27.3%
1 RM	.8074±.2730	.8159±.2253	1.1%	.7815±.3511	.9633±.3006 †	23.8%
Ballistic/MVC	.9100±.2411	.8242±.2167	-9.4%	.9629±.2045	.9335±.1715	-3.1%
Ballisistic/1 RM	.7993±.2264	.7920±.2676	-0.9%	.8956±.3629	.8399±.2173	-6.2%
1 RM/MVC	1.212±.4201	1.081±.2038	-10.8%	1.172±.3326	1.180±.3909	0.7%

Values are mean ± SD, and % difference. Significantly different from ballistic training arm and heavy resistance pre-training † $p \leq 0.05$ Significant main effect for time collapsed across groups (post vs. pre-training values) * $p \leq 0.05$,** $p \leq 0.01$.

Table 6. Antagonist electromyography (mV)

Measurements	Ballistic Training Arm			Heavy Resistance Training Arm		
	Pre-training	Post-training	Difference	Pre-training	Post-training	Difference
Ballistic action	.0622±.0191	.0814±.0193	30.9%	.0792±.0247	.0760±.0267	-4.0%
MVC	.1342±.0472	.1151±.0349	-14.2%	.1430±.0453	.1368±.0597	-4.3%
1 RM	.0922±.0132	.0995±.0208	7.9%	.0978±.0210	.1116±.0368	14.1%
Ballistic/MVC *	.4875±.1397	.7279±.1608 †	49.3%	.5635±.1217	.6121±.1987	8.6%
Ballistic/1 RM	.6896±.2441	.8362±.2228	21.3%	.8301±.2788	.6611±.2782	20.4%
1 RM/MVC **	.7619±.2885	.9119±.2621	19.7%	.7450±.3146	.9210±.3939	23.6%

Values are mean ± SD, and % difference. Significantly different from ballistic & heavy resistance pre-training arm † p≤0.05, Significant main effect for time collapsed across groups (post vs. pre-training values) * p≤0.05, ** p≤0.01.

Table 7. Antagonist/agonist coactivation ratios of electromyography

Measurements	Ballistic Training Arm			Heavy Resistance Training Arm		
	Pre-training	Post-training	Difference	Pre-training	Post-training	Difference
Ballistic action	.1115±.0515	.1376±.0391 †	23.4%	.1304±.04126	.1008±.0360	-22.7%
MVC *	.2091±.0940	.1601±.0751	-23.4%	.2246±.0672	.1717±.0877	-23.6%
1 RM	.1256±.0503	.1271±.0322	1.2%	.1414±.0520	.1199±..0364	-15.2%
Ballistic/MVC *	.5760±.2348	.9475±.3348 ‡	64.5%	.6077±.1730	.6624±.2120	9.0%
Ballistic/1 RM	.9016±.3372	1.162±.5530	28.9%	1.010±.3737	.8410±.1492	-16.7%
1 RM/MVC *	.6703±.2537	.8719±.2706	30.1%	.6510±.2334	.8012±..2825	23.1%

Values are mean ± SD, and % difference. Significantly different from ballsitc pre & heavy resistance post-training arm † $p \leq 0.05$, Significantly different from ballsitc pre & heavy resistance pre & post-training arm ‡ $p \leq 0.05$. Significant main effect for time collapsed across groups (post vs. pre-training values) * $p \leq 0.05$.

Table 8. Isometric Evoked Contractile Properties (ECP)

Measurements	Ballistic Training Arm			Heavy Resistance Training Arm		
	Pre-training	Post-training	Difference	Pre-training	Post-training	Difference
Peak Torque (N·m)	8.9±0.8	9.2±1.0	3.4%	8.2±0.7	10.5±0.9†‡	28.0%
TPT (ms)	60.8±2.1	58.0±2.3	-3.2%	61.1±1.7	61.6±2.1	0.8%
Rise Time (ms)	38.6±1.4	39.0±1.9	1.0%	39.3±1.3	41.5±1.6	5.6%
MRTD (N·m·s^{-1})	216.7±17.2	224.3±14.7	3.5%	205.0±17.0	242.7±21.2	18%
ARTD (N·m·s^{-1})	147.4±13.4	157.1±12.4	6.6%	136.3±12.6	171.7±16.0	26.6%
MRTR (N·m·s^{-1})	-94.8±5.9	-109.0±12.7	15%	-97.2±7.9	-100.8±9.0	3.7%
TTI (N·m·s) *	1.16±0.12	1.18±0.13	1.7%	1.06±0.10	1.41±0.13†‡	33.0%
1/2 Relaxation Time (ms)	63.9±6.4	64.3±6.3	0.6%	65.8±6.7	72.8±6.0	10.6%
TPT + 1/2 RT (ms)	124.7±7.4	122.3±6.9	-1.9%	126.9±7.8	134.4±6.0	5.9%
TWT/MVC	0.17±0.02	0.17±0.02	0.0%	0.16±.0.02	0.17±0.01	6.3%

Values are mean ± SD, and % difference. Significantly different from ballistic training arm † $p \leq 0.05$. Significantly different from pre-training value ‡ $p \leq 0.01$. Significant main effect for time collapsed across groups (post vs. pre-training values) * $p \leq 0.05$

Table 9. Control (N=6) and training (N=9) subject's fiber areas

Group		Type I	Type IIa	Type IIb
CONTROL				
	pre	3881±111	5607±167	5802±139
	post	3538±144	5285±351	5271±379
	%	-8.8	-5.70	-9.2
TRAINING				
Heavy resistance				
	pre	4356±161	5371±163	5261±241
	post	5575±305 **†	7677±369 **†	7436±442 **†
	%	28.0	43.0	41.4
Ballistic				
	pre	4273±155	5226±185	5284±245
	post	4071±98	5658±207	5403±254
	%	-4.7	8.3	3.0

Fiber area values are means ± SE. Significantly different from pre-training ** (p≤0.01). Significantly different from ballistic arm post-training † (p≤0.05). A small biopsy sample size in one pre-training arm of 5 subject's resulted in the use of the other arm's pre-training values to determine fiber type.

Chapter II: Figure Legends

Figure 1. Diagram of experimental testing and training sessions time log

Figure 2. Testing periods of subjects heavy resistance actions weight lifted for a 6 RM (Kg) and a single ballistic actions peak torque (N·m) during the course of the training period.

Figure 3. Ballistic testing and training apparatus

Figure 4. Recording of a subjects kinetic and kinematic performances during a ballistic action with a load equal to 10% of the subject's MVC. Traces of torque, velocity, acceleration, power, rate of force development (RTD), and displacement are depicted. Arrows mark the approximate beginning (increase in torque and EMG activation) and end (torque = 0) of the analysis window for EMG and the depicted measurements. EMG started ~0-100 ms before torque. Ballistic actions were performed on a specially designed arm apparatus (Fig. 3), where the forearm was strapped to a brace, and the subject's body to an adjustable chair. A steel shaft was mounted to the center of rotation of the forearm brace and a wheel acting as a pulley to lift a weight equivalent to a percentage of the subject's MVC.

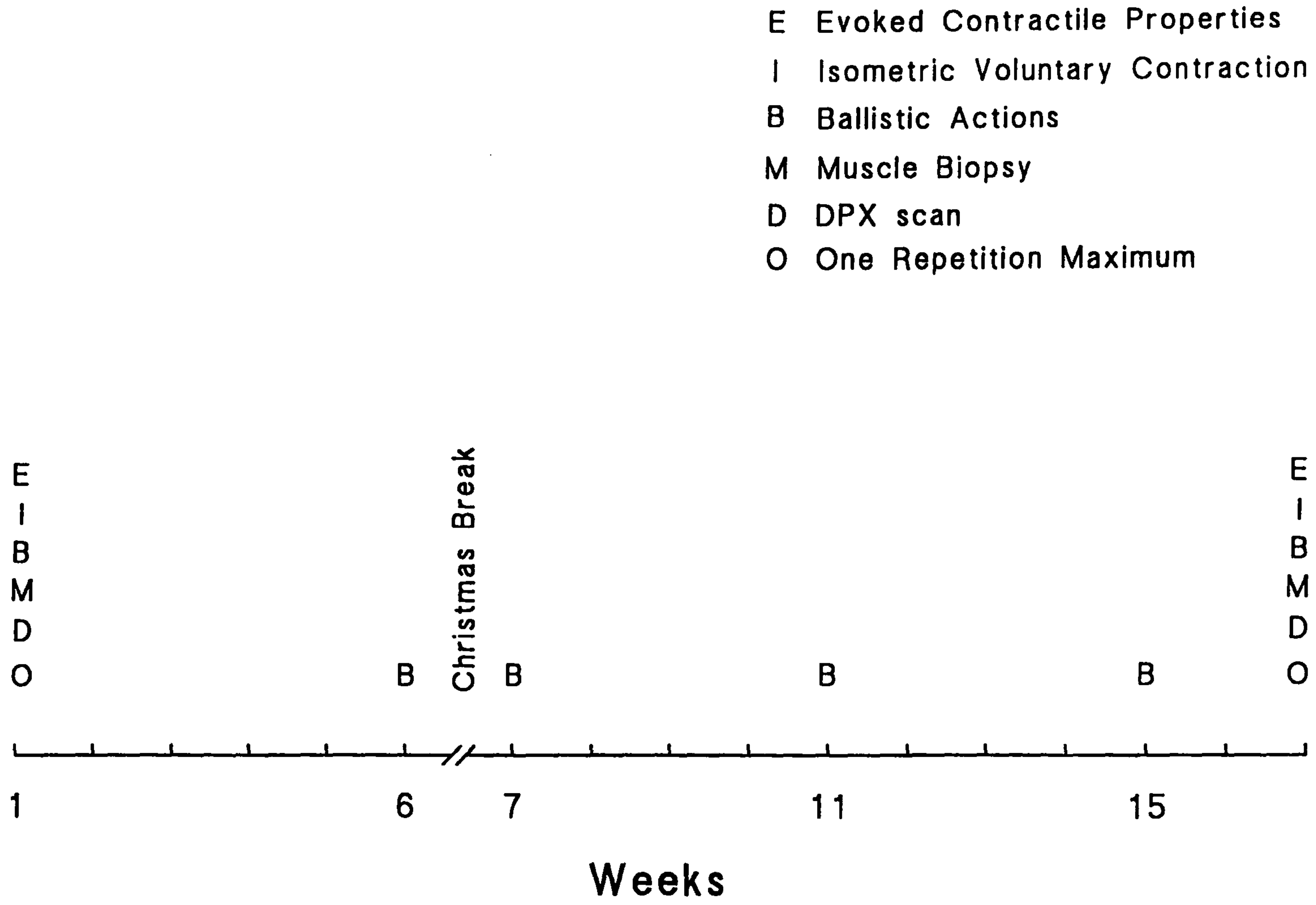
Figure 5. Torque and electromyographic (EMG) recordings from agonist (extensors-triceps), and antagonist (flexor-biceps) muscles during heavy resistance (85% 1 RM) and ballistic (10% MVC) elbow extensions. Ballistic actions were performed on the same device as displayed in figure 3 and described in Figure 4 with a load equivalent to 10% of the subject's MVC. Heavy resistance actions were performed from an over the shoulder wall mounted pulley system with an 85% 1 RM load. A long (Fig. A) and short (Fig. B) time line demonstrate the large differences in the time of action and muscle activity. Note the constant burst activity pattern during both actions, but the much more abrupt onset of the ballistic action.

Figure 6. Evoked isometric twitch torque recording with measurements of twitch peak torque (PT), maximum rate of torque development (MRTD), maximum rate of torque relaxation (MRTR), and torque-time integral (impulse). PT was taken as the highest torque reading. MRTD and MRTR were taken as the mean of two points on the torque curve given the highest slope value. Impulse (area under curve) started when 2% of PT was reached upon the rise of the torque, and ended when 2% of PT was reached on the decent phase of the torque trace.

Figure 7. Evoked isometric twitch torque recording with measurements of time to peak torque (TPT), rise time (RT), and ½ relaxation time (½ RT) displayed as analyzed. Rise time defined as the time from 10%-90% of PT. TPT started at 2% of PT and ended at PT. HRT was defined as the time from PT to half of the peak torque value upon the decent of the torque tracing.

Figure 8. DPX whole body pre (a) and post-training (b). The subject's right arm is the heavy resistance arm, notice the larger arm size compared to the left (ballistic trained) arm. There was no significant difference in arm size pre-training.

Figure 9. DPX regional arm scans pre (a) and post-training (b). The subject's right arm is the heavy resistance arm, notice the larger arm size compared to the left (ballistic trained) arm. There was no significant difference in arm size pre-training.


E Evoked Contractile Properties
I Isometric Voluntary Contraction
B Ballistic Actions
M Muscle Biopsy
D DPX scan
O One Repetition Maximum
E
I
B
M
D
O
B
Christmas Break
B
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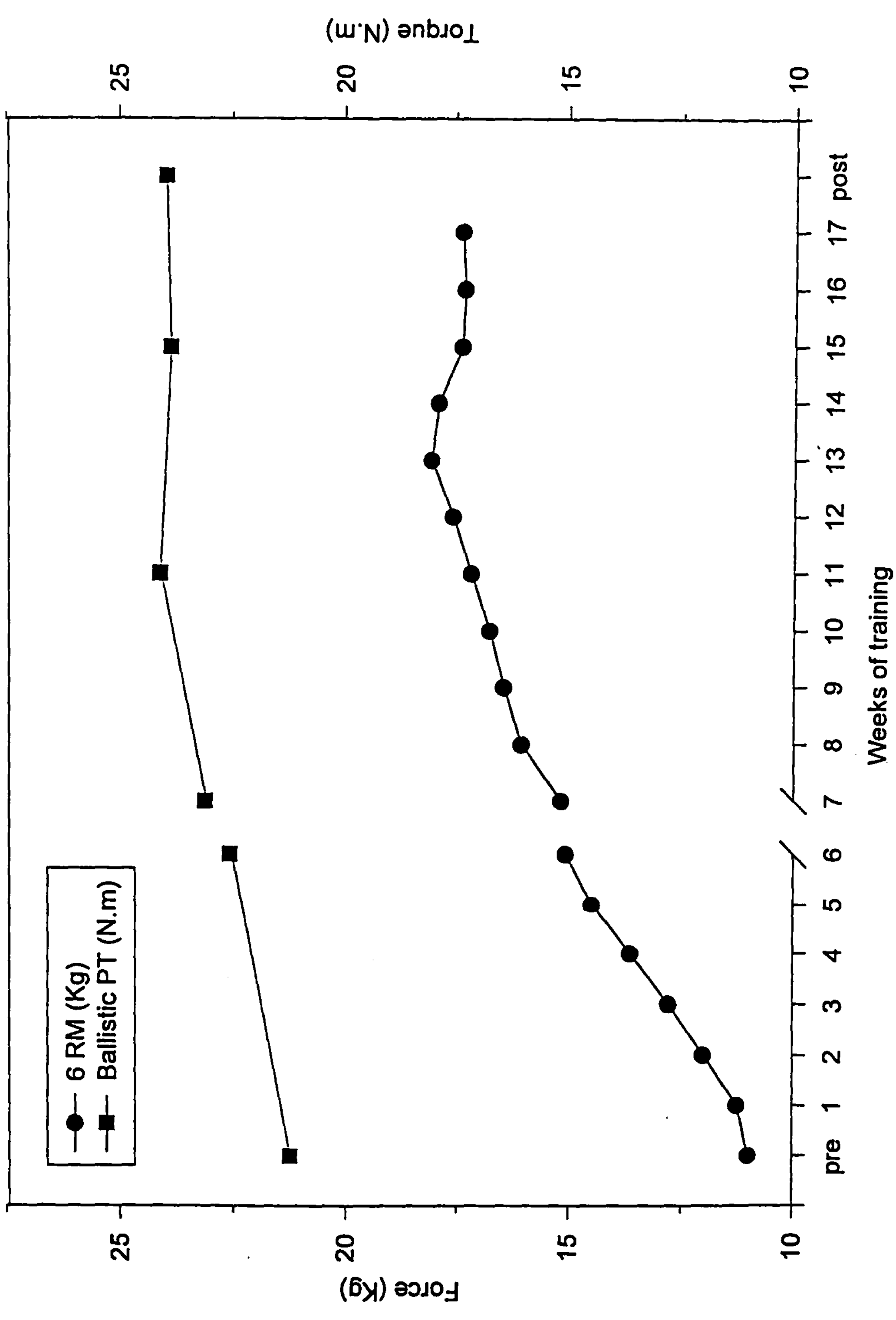
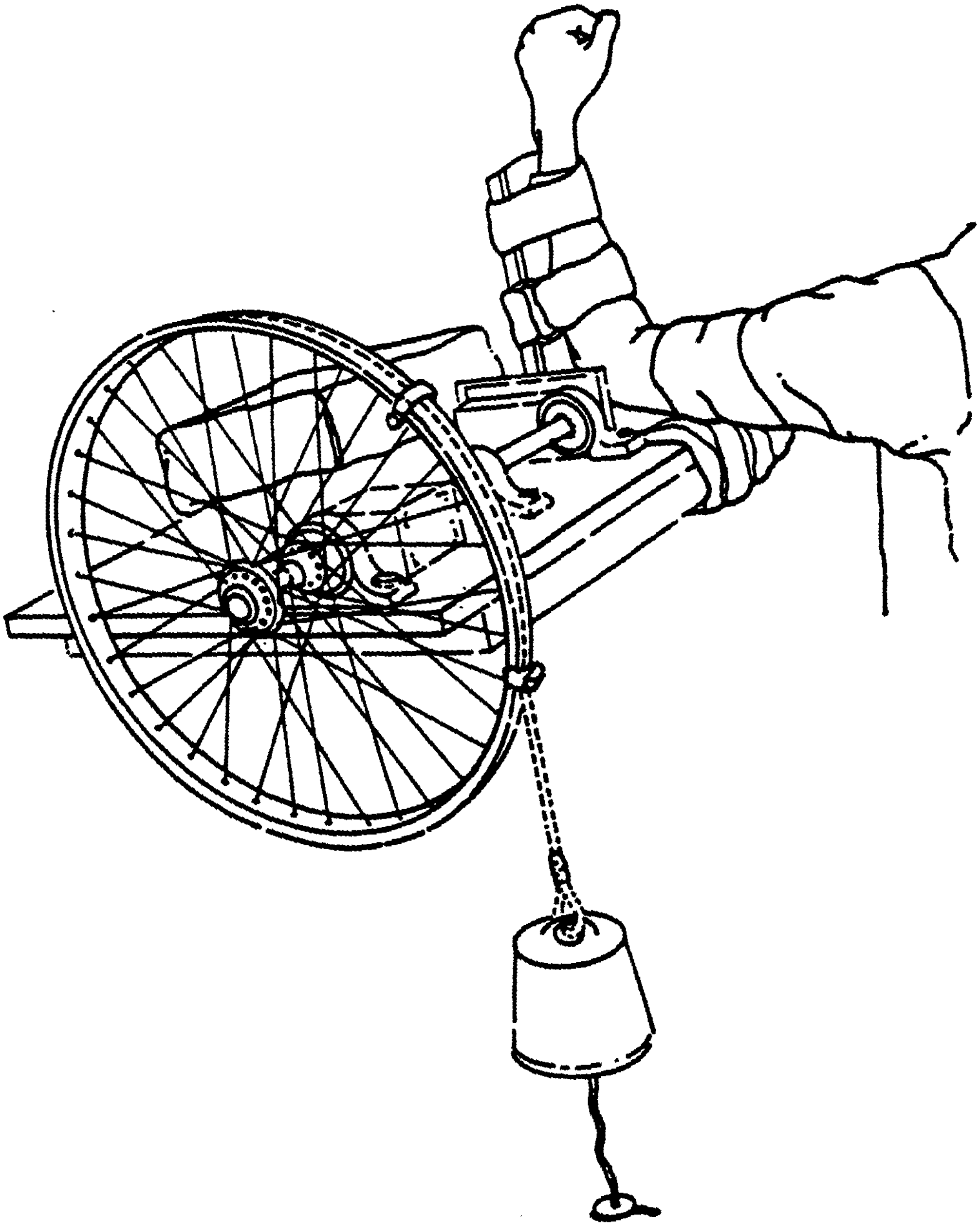
1
6
7
11
15
Weeks

Figure 1/


6 RM (Kg)
Ballistic PT (N.m)
Force (Kg)
Torque (N.m)
Weeks of training
10
15
20
25
pre
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
post



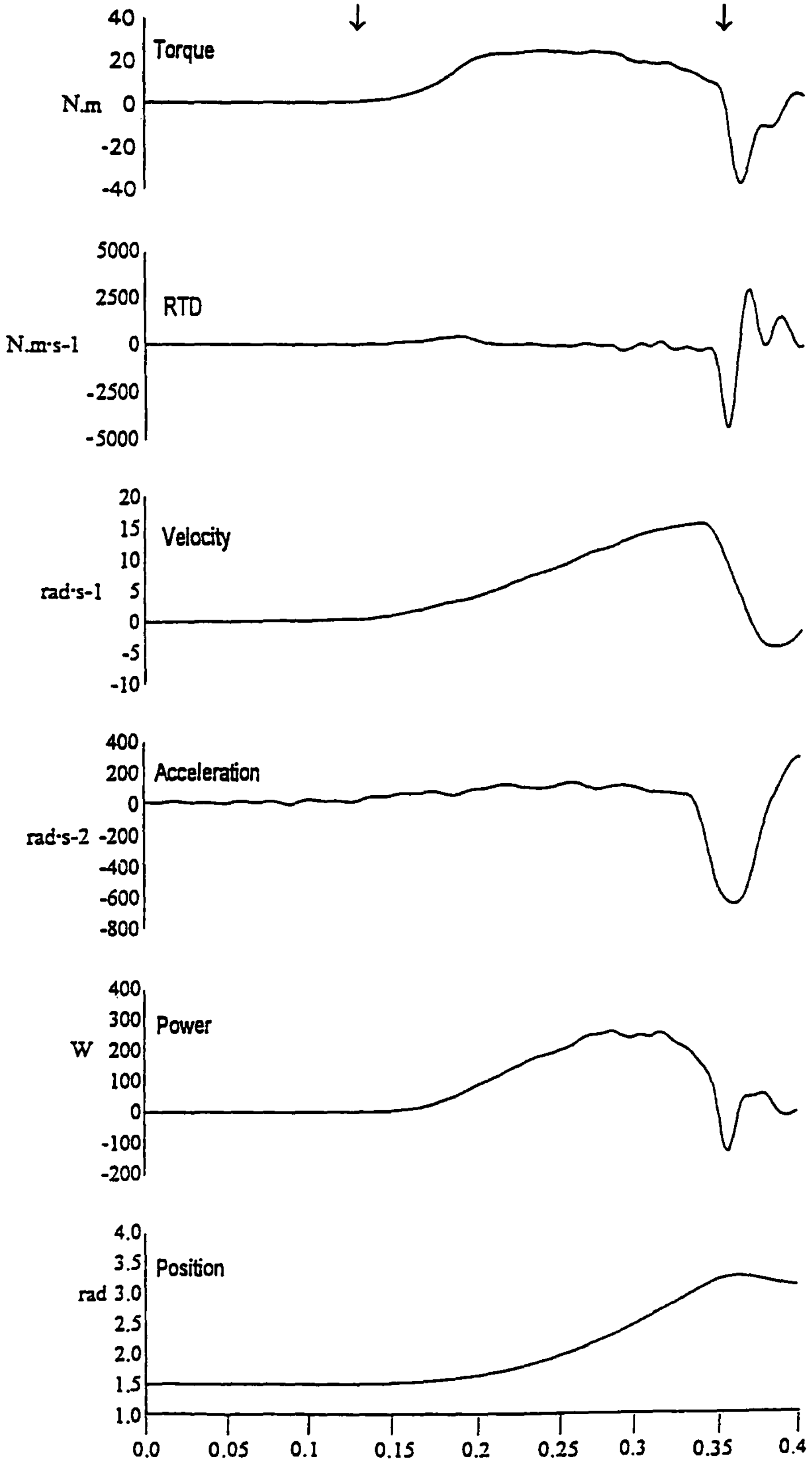

↓
↓
40
20
Torque
N.m 0
-20
-40
5000
2500
RTD
N.m·s-1 0
-2500
-5000
20
15
Velocity
10
rad·s-1 5
0
-5
-10
400
200
Acceleration
0
rad·s-2 -200
-400
-600
-800
400
300
Power
W 200
100
0
-100
-200
4.0
3.5
Position
rad 3.0
2.5
2.0
1.5
1.0
0.0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

Figure 5/

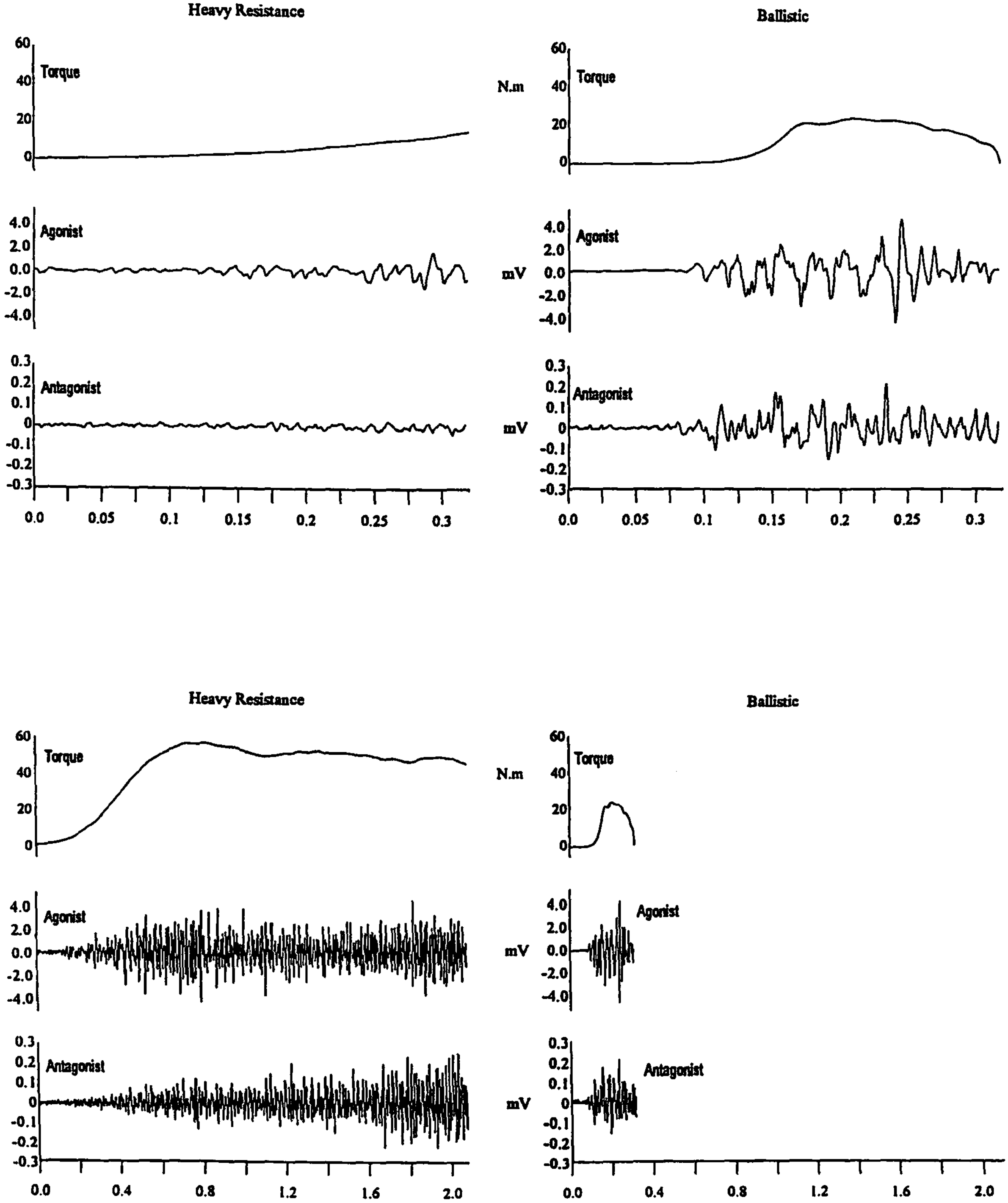

Heavy Resistance
Ballistic
Torque
Agonist
Antagonist
N.m
mV
60
40
20
0
4.0
2.0
0.0
-2.0
-4.0
0.3
0.2
0.1
-0.1
-0.2
-0.3
0.0
0.05
0.1
0.15
0.2
0.25
0.3
0.4
0.8
1.2
1.6
2.0

Figure 6/

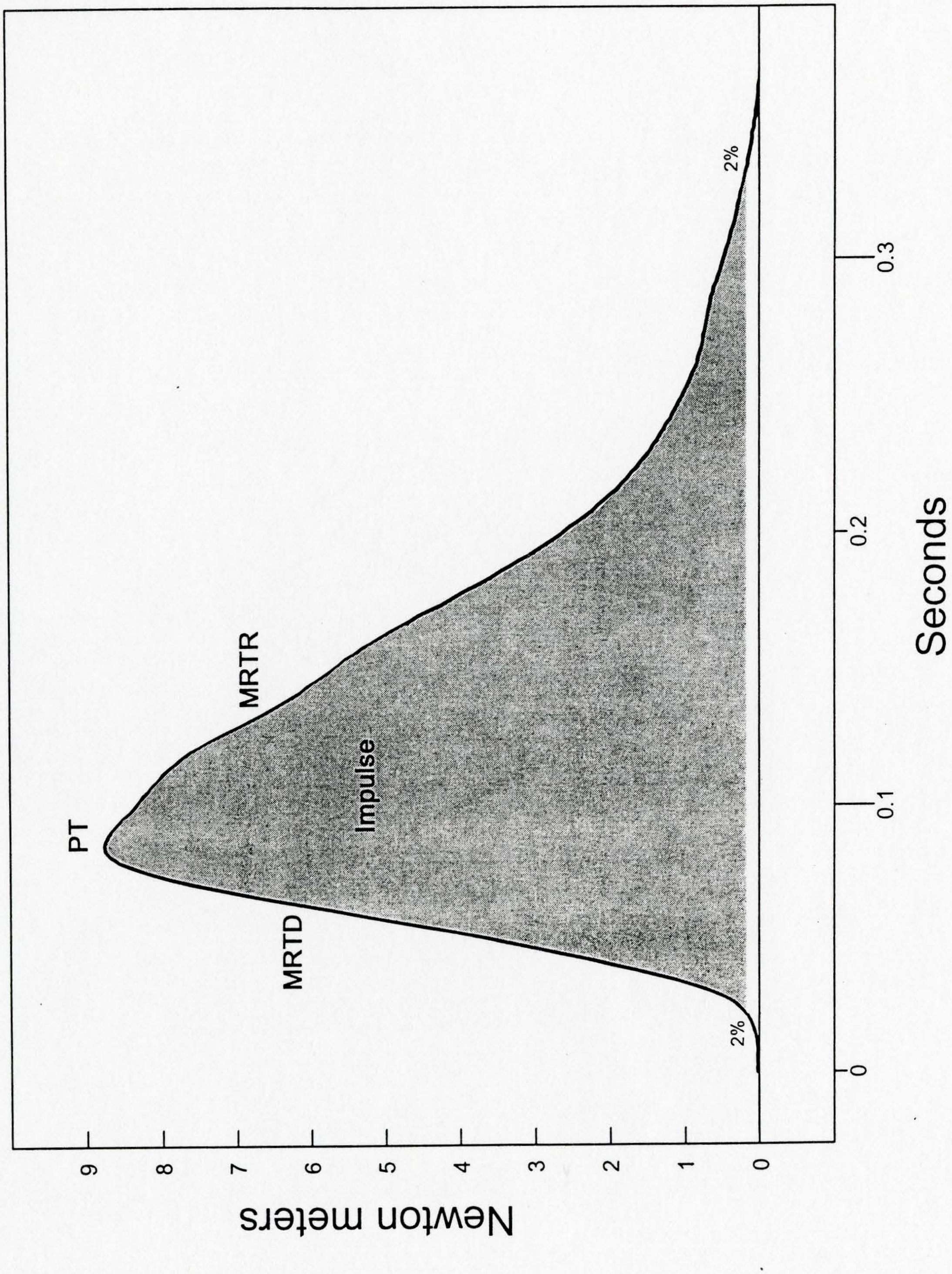

Newton meters
0
1
2
3
4
5
6
7
8
9
Seconds
0
0.1
0.2
0.3
PT
MRTD
MRTR
Impulse
2%
2%

Figure 7/

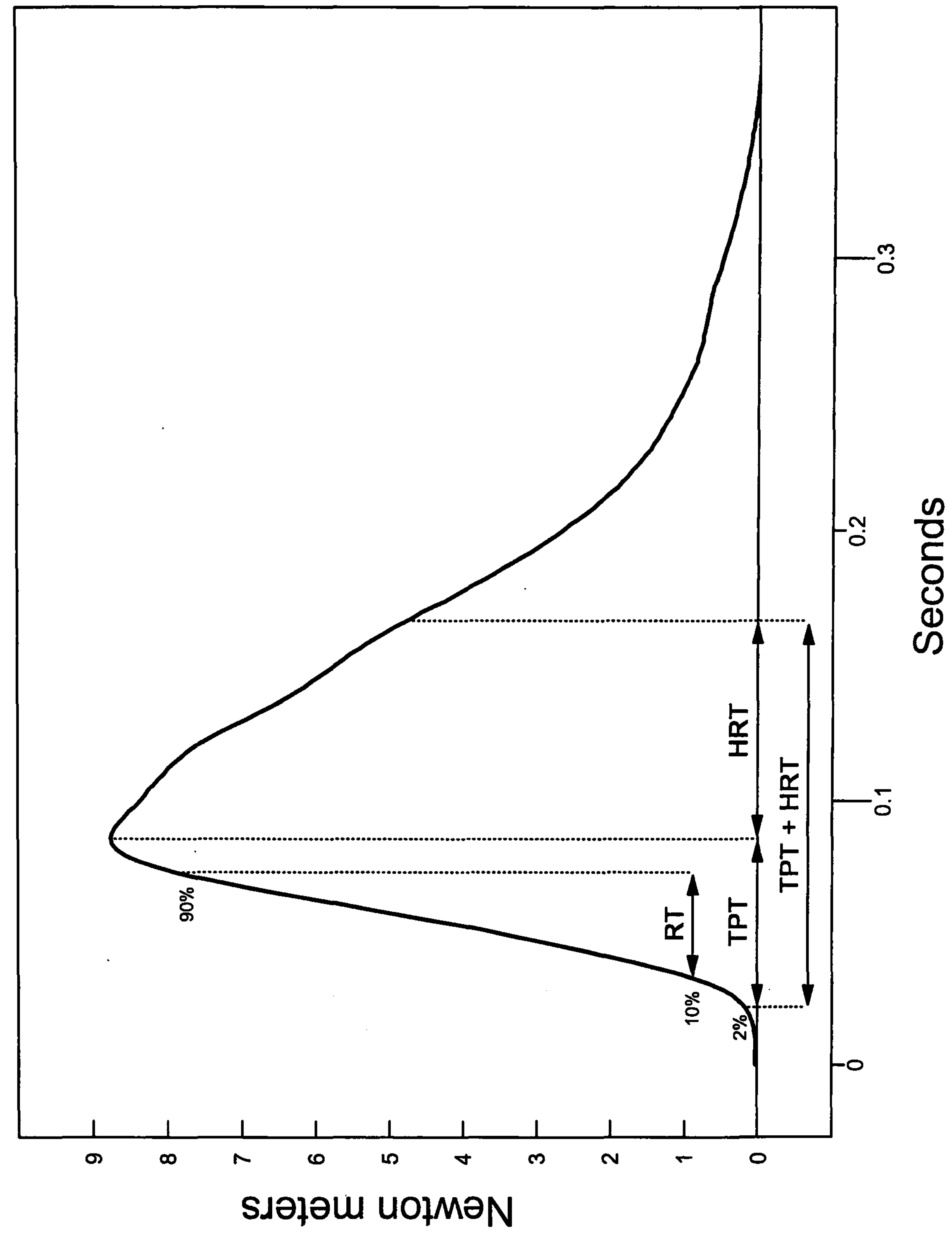

Newton meters
0
1
2
3
4
5
6
7
8
9
Seconds
0
0.1
0.2
0.3
2%
10%
90%
RT
TPT
HRT
TPT + HRT

Figure 8/

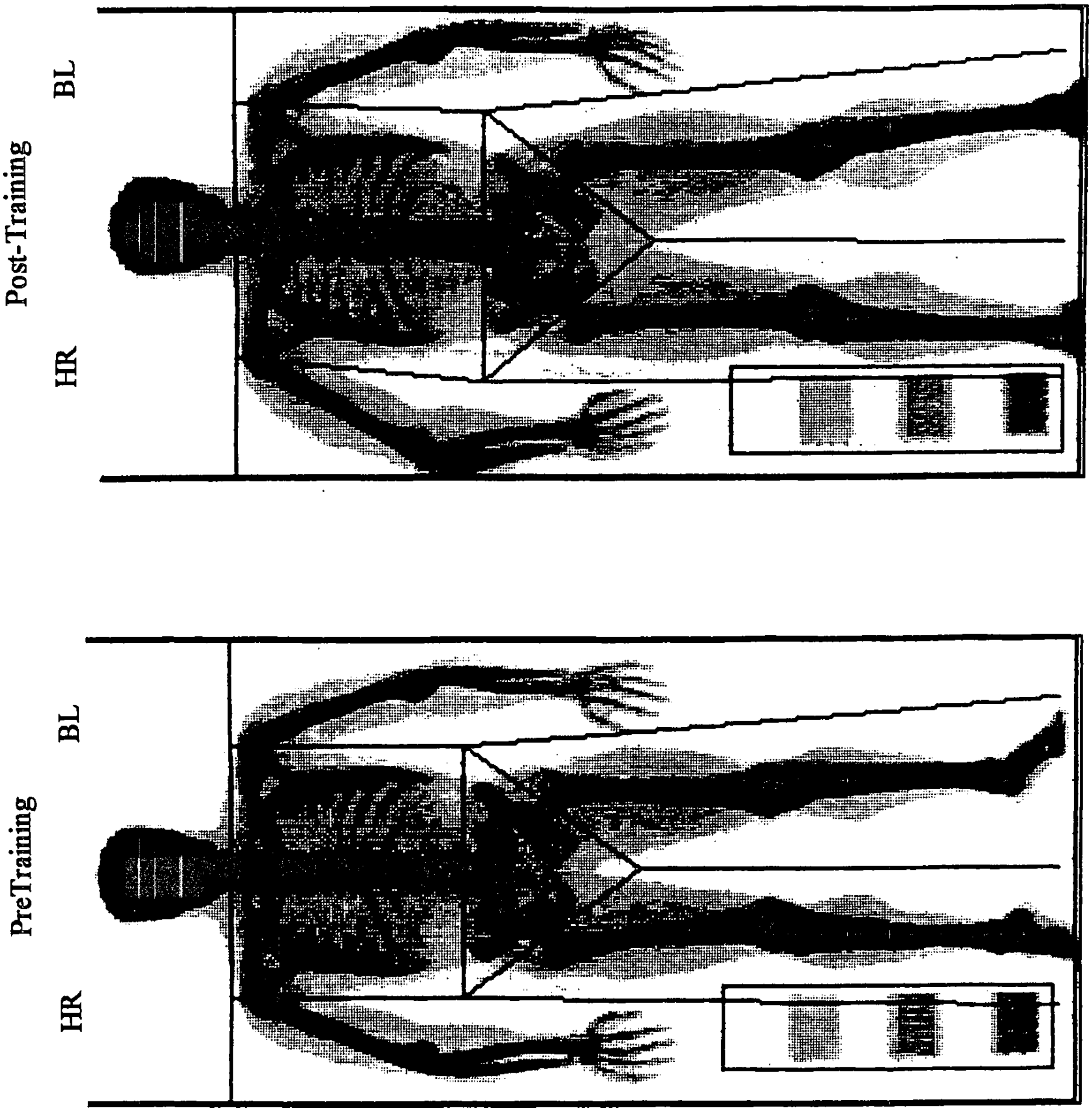
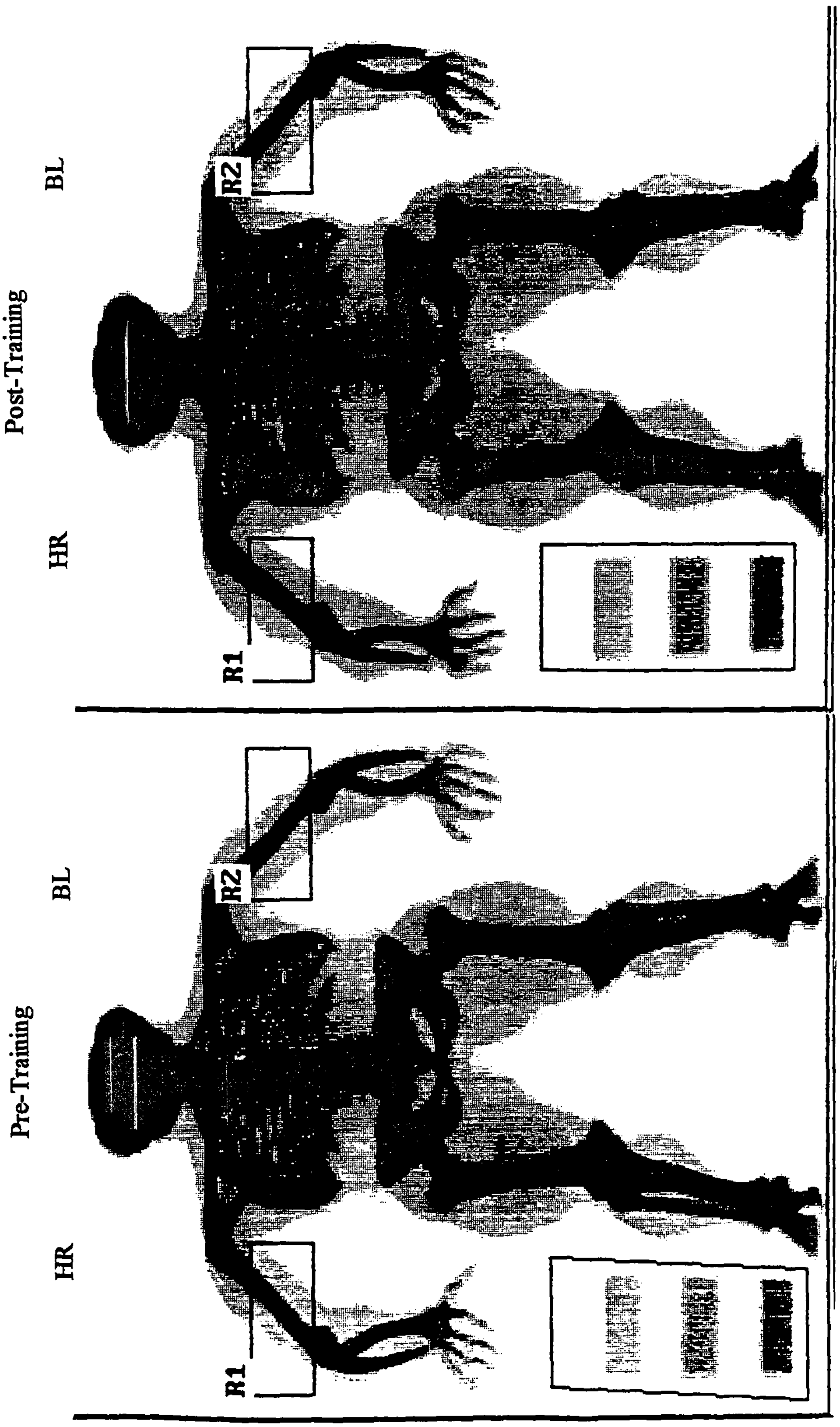


Figure 9/



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APPENDIX A

Spreadsheets of Training Group Raw Data

BALLISTIC ACTIONS

Ballistic training arm

Pre-training

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	MRTD (N.m.s-1)	Peak Power (watts)
Tony A.	212.7	12.27	125.7	22.11	102.3	546.0	171.74
Mike B.	193.3	12.44	121.81	17.54	70.9	500.0	135.33
Shawn C.	184.6	13.07	131.56	20.23	78.9	466.0	150.12
Nick C.	232.7	11.73	107.11	22.79	128.4	451.0	173.68
John C.	200.0	12.36	143.83	22.83	75.6	785.0	165.61
Jay D.	200.6	12.62	128.98	21.29	93.0	576.0	157.83
Ryan K.	218.7	13.14	124.91	22.88	157.2	446.0	204.97
Jay M.	189.9	12.83	133.9	20.67	95.0	583.0	161.51
Thoi N.	197.3	12.9	123.91	20.91	88.3	577.0	145.49
Mean	203.31	12.6	126.86	21.25	98.84	547.78	162.92
S.D.	15.3	0.45	9.96	1.71	27.77	104.8	20.08

Post-training

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	MRTD (N.m.s-1)	Peak Power (watts)
Tony A.	209.3	12.62	118.54	20.76	121.7	383.0	167.67
Mike B.	187.9	15.69	160.24	24.13	89.0	1027.0	218.93
Shawn C.	199.3	12.71	111.93	18.59	95.0	386.0	157.52
Nick C.	200.0	13.23	124.86	28.57	87.6	842.0	265.41
John C.	194.6	13.39	117.58	26.11	91.6	647.0	219.18
Jay D.	204.0	13.54	125.11	20.38	90.3	514.0	190.64
Ryan K.	193.3	13.42	127.16	29.67	89.0	759.0	226.14
Jay M.	204.0	14.35	141.46	22.55	127.7	582.0	190.64
Thoi N.	180.6	16.32	160.05	24.91	118.4	531.0	265.24
Mean	197.0	13.92	131.88	23.96	101.14	630.11	211.26
S.D.	8.91	1.29	17.98	3.76	16.39	213.77	38.45

BALLISTIC ACTIONS

Heavy Resistance training arm

Pre-training

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	MRTD (N.m.s-1)	Peak Power (watts)
Tony A.	210.0	12.92	121.44	23.22	110.4	414.0	181.6
Mike B.	208.0	12.9	114.06	19.27	164.5	319.0	136.99
Shawn C.	206.0	12.06	122.94	22.74	78.9	708.0	142.51
Nick C.	233.4	12.1	114.11	25.44	120.4	585.0	196.49
John C.	223.4	12.27	105.45	19.7	135.1	362.0	179.26
Jay D.	207.3	12.16	127.88	17.01	88.3	494.0	123.45
Ryan K.	204.7	12.88	126.22	23.89	95.6	591.0	163.14
Jay M.	214.0	11.96	122.94	22.21	134.4	445.0	168.53
Thoi N.	194.6	14.43	136.68	20.81	91.0	570.0	179.73
Mean	211.27	12.63	121.3	21.59	113.18	498.67	163.52
S.D.	11.3	0.78	9.12	2.62	27.88	125.46	24.24

Post-training

Subjects	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	MRTD (N.m.s-1)	Peak Power (watts)
Tony A.	200.6	13.95	136.55	25.39	115.0	493.0	224.41
Mike B.	185.9	14.49	126.05	19.12	88.3	406.0	182.67
Shawn C.	197.3	12.78	118.16	21.2	78.2	561.0	162.87
Nick C.	226.7	12.18	109.29	25.48	121.1	549.0	195.2
John C.	191.9	14.31	141.62	31.07	86.9	726.0	250.38
Jay D.	199.3	12.95	121.27	18.93	69.6	514.0	133.92
Ryan K.	195.3	13.0	123.88	23.46	77.6	647.0	178.58
Jay M.	226.7	12.67	135.25	24.95	113.7	774.0	187.64
Thoi N.	165.2	16.27	182.14	27.6	91.6	575.0	251.05
Mean	198.77	13.62	132.69	24.13	93.56	582.78	196.3
S.D.	19.1	1.27	21.09	3.96	18.59	115.61	39.21

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BALLISTIC ELECTROMYOGRAPHY

Ballistic training arm

Pre-training

Subjects	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	55.5	292.3	.4256	.975	260.8	.0654	.130	0.154	0.134
Mike B.	49.5	259.5	.6850	1.940	262.2	.0898	.190	0.131	0.098
Shawn C.	41.5	244.1	.5748	1.308	277.6	.0879	.232	0.153	0.177
Nick C.	61.5	330.4	.4915	1.174	303.6	.0420	.077	0.085	0.065
John C.	40.1	266.2	.7947	1.924	241.4	.0589	.132	0.074	0.069
Jay D.	66.2	297.6	.3862	1.137	260.8	.0770	.161	0.199	0.141
Ryan K.	56.2	340.4	.9975	3.066	299.6	.0479	.125	0.048	0.041
Jay M.	114.4	331.1	.7333	2.725	327.7	.0385	.143	0.052	0.052
Thoi N.	64.2	287.6	.4910	1.215	303.6	.0524	.118	0.107	0.097
Mean	61.01	294.36	.6199	1.7182	281.92	.0622	.1452	0.112	0.097
S.D.	22.06	34.21	.1993	.7525	28.04	.0191	.0447	0.051	0.046

Post-training

Subjects	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	53.5	297.6	.6894	1.647	246.8	.0823	.182	0.119	0.110
Mike B.	26.8	236.1	.8854	2.199	246.8	.1037	.247	0.117	0.113
Shawn C.	33.4	256.8	.6312	1.167	224.7	.0937	.166	0.148	0.143
Nick C.	46.1	272.2	.7279	1.409	252.1	.0839	.178	0.115	0.126
John C.	78.2	290.9	.6994	1.832	268.9	.0774	.248	0.111	0.135
Jay D.	43.5	268.9	.3084	.696	273.5	.0654	.122	0.212	0.175
Ryan K.	32.1	244.1	.6027	1.151	240.1	.1060	.178	0.176	0.155
Jay M.	37.5	274.9	.5190	1.190	252.1	.0438	.087	0.084	0.073
Thoi N.	53.5	257.5	.4925	1.188	222.7	.0766	.151	0.155	0.127
Mean	44.96	266.56	.6173	1.3865	247.52	.0814	.1733	0.138	0.129
S.D.	15.57	20.22	.1647	.4451	17.20	.0193	.0523	0.039	0.029

BALLISTIC ELECTROMYOGRAPHY

Heavy resistance training arm

Pre-training

Subjects	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	42.1	279.6	.6063	1.129	266.2	.0872	.268	0.144	0.237
Mike B.	18.1	303.6	.6113	1.480	317	.1041	.243	0.170	0.164
Shawn C.	49.5	274.9	.5397	1.167	287.6	.1125	.258	0.208	0.221
Nick C.	91	355.1	.5959	1.399	353.8	.0521	.131	0.087	0.093
John C.	15.4	269.5	.8200	1.698	250.8	.0820	.151	0.100	0.089
Jay D.	78.9	315.7	.4552	1.397	309	.0500	.111	0.110	0.079
Ryan K.	34.1	257.5	.5802	1.191	323.7	.0887	.254	0.153	0.213
Jay M.	15.4	275.5	.4940	1.368	203.3	.0439	.085	0.089	0.062
Thoi N.	40.8	254.8	.8265	1.758	224.7	.0923	.233	0.112	0.133
Mean	42.81	287.36	.6143	1.3984	281.79	.0792	.1926	0.130	0.144
S.D.	27.07	32.18	.1296	.2225	49.47	.0247	.072	0.041	0.067

Post-training

Subjects	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	36.8	260.8	.6766	1.586	246.1	.0520	.114	0.077	0.072
Mike B.	34.8	239.4	.7401	1.782	224	.1011	.179	0.137	0.100
Shawn C.	30.1	244.8	.6114	1.349	244.1	.0875	.209	0.143	0.155
Nick C.	30.1	280.9	.8209	1.754	283.6	.0545	.115	0.066	0.066
John C.	56.2	263.5	.8495	2.683	268.2	.0603	.126	0.071	0.047
Jay D.	34.1	245.4	.6528	1.400	234.1	.0931	.202	0.143	0.145
Ryan K.	26.1	242.1	1.0492	1.177	235.4	.0774	.186	0.074	0.158
Jay M.	12.7	258.2	.5856	1.290	256.2	.0383	.084	0.065	0.065
Thoi N.	38.1	223.4	.9149	1.669	191.3	.1201	.195	0.131	0.117
Mean	33.22	250.94	.7668	1.6321	242.56	.076	.1566	0.101	0.103
S.D.	11.51	16.75	.1542	.4477	26.55	.0267	.0466	0.036	0.043

MVC DATA

Ballistic training arm

Pre-training

Subject	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	TPT (ms)	PT (N.m)	Pk. RTD (N.m/sec)	TIME Pk. RTD (ms)	AVERAGE RTD (N.m/sec)
Tony A.	28.80	2.004	0.49	1.15	2.004	.1568	0.34	0.52	55.8	605.5	66.8	107.0
Mike B.	44.10	2.004	0.92	2.04	2.004	.1367	0.41	1.19	43.2	727.3	64.2	36.4
Shawn C.	24.70	2.004	0.63	1.43	2.004	.231	0.52	0.80	43.5	595.9	46.2	54.1
Nick C.	25.40	2.004	0.62	1.46	2.004	.0746	0.20	1.15	67.7	553.1	75.6	58.9
John C.	34.10	2.004	0.96	2.52	2.004	.0907	0.32	1.68	59.9	380.7	62.9	35.6
Jay D.	25.40	2.004	0.57	1.35	2.004	.1349	0.29	0.99	49.0	720.3	56.9	49.4
Ryan K.	24.70	2.004	1.30	2.63	2.004	.1647	0.31	1.89	63.3	559.2	58.2	33.5
Jay M.	32.10	2.004	0.51	1.23	2.004	.1227	0.49	0.66	47.2	457.9	50.2	72.0
Thoi N.	78.20	2.004	0.42	1.21	2.004	.0961	0.21	1.05	47.9	210.4	123.8	45.6
Mean	35.28	2.004	0.71	1.67	2.004	0.13	0.34	1.104	53.1	534.5	67.2	54.7
S.D.	17.29	.000	0.29	0.58	.000	0.05	0.11	0.449	8.9	164.3	23.0	23.2

	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	0.32	0.29
Mike B.	0.15	0.20
Shawn C.	0.37	0.36
Nick C.	0.12	0.14
John C.	0.09	0.13
Jay D.	0.24	0.21
Ryan K.	0.13	0.12
Jay M.	0.24	0.40
Thoi N.	0.23	0.17
Mean	0.21	0.23
S.D.	0.09	0.10

MVC DATA

Ballistic training arm

Post-training

Subject	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	TPT (ms)	PT (N.m)	Pk. RTD (N.m/sec)	TIME Pk. RTD (ms)	AVERAGE RTD (N.m/sec)
Tony A.	20.10	2.004	0.64	1.97	2.004	0.11	0.28	1.172	60.6	553.5	115.0	51.7
Mike B.	34.80	2.004	0.85	2.22	2.004	0.12	0.38	1.468	43.9	500.7	107.0	29.9
Shawn C.	24.70	2.004	0.58	1.80	2.004	0.20	0.46	0.484	46.4	541.8	118.4	95.8
Nick C.	12.70	2.004	0.89	1.63	2.004	0.09	0.23	1.950	66.1	641.7	77.6	33.9
John C.	56.00	2.004	0.92	1.97	2.004	0.11	0.27	0.428	57.6	694.1	164.5	134.6
Jay D.	20.70	2.004	0.67	1.60	2.004	0.11	0.29	1.324	46.0	600.2	88.3	34.7
Ryan K.	34.10	2.004	1.01	2.10	2.004	0.11	0.26	0.893	59.3	846.4	115.7	66.4
Jay M.	26.80	2.004	0.66	1.45	2.004	0.07	0.19	0.414	56.3	693.7	66.9	136.0
Thoi N.	8.70	2.004	0.64	1.50	2.004	0.11	0.24	0.351	49.4	551.8	93.0	140.6
Mean	26.51	2.004	0.76	1.80	2.004	0.12	0.29	0.943	53.9	624.9	105.2	80.4
S.D.	14.06	.000	0.16	0.28	.000	0.03	0.08	0.570	7.7	107.4	28.6	47.1

	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	0.17	0.14
Mike B.	0.14	0.17
Shawn C.	0.35	0.26
Nick C.	0.10	0.14
John C.	0.12	0.14
Jay D.	0.17	0.18
Ryan K.	0.11	0.12
Jay M.	0.11	0.13
Thoi N.	0.17	0.16
Mean	0.16	0.16
S.D.	0.08	0.04

MVC DATA

Heavy resistance training arm

Pre-training

Subject	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	TPT (ms)	PT (N.m)	Pk. RTD (N.m/sec)	TIME Pk. RTD (ms)	AVERAGE RTD (N.m/sec)
Tony A.	25.40	2.004	0.56	1.16	2.004	.1193	0.28	0.89	60.0	540.9	81.6	67.4
Mike B.	30.10	2.004	0.71	2.76	2.004	.2142	0.47	0.13	41.5	600.7	43.5	323.1
Shawn C.	30.80	2.004	0.67	1.28	2.004	.1827	0.39	1.11	54.1	675.3	49.5	48.6
Nick C.	21.40	2.004	0.83	2.14	2.004	.0795	0.18	1.72	70.2	495.0	86.9	40.7
John C.	56.80	2.004	0.82	2.01	2.004	.1415	0.56	1.39	61.6	621.2	66.9	44.2
Jay D.	28.10	2.004	0.38	1.34	2.004	.1193	0.30	1.23	44.6	658.7	41.5	36.3
Ryan K.	40.10	2.004	0.83	1.88	2.004	.1964	2.02	1.69	52.9	828.6	42.2	31.2
Jay M.	28.10	2.004	0.46	1.14	2.004	.1032	0.25	1.54	54.6	571.0	52.8	35.6
Thoi N.	29.40	2.004	0.66	1.59	2.004	.1305	0.30	1.02	47.0	324.4	254.2	46.0
Mean	32.24	2.004	0.66	1.70	2.004	0.14	0.53	1.192	54.1	590.6	79.9	74.8
S.D.	10.48	.000	0.16	0.54	.000	0.05	0.57	0.494	9.0	138.0	67.5	93.7

	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	0.21	0.24
Mike B.	0.30	0.17
Shawn C.	0.27	0.31
Nick C.	0.10	0.09
John C.	0.17	0.28
Jay D.	0.31	0.22
Ryan K.	0.24	1.08
Jay M.	0.22	0.22
Thoi N.	0.20	0.19
Mean	0.22	0.31
S.D.	0.07	0.30

MVC DATA

Heavy resistance training arm

Post-training

Subject	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	TPT (ms)	PT (N.m)	Pk. RTD (N.m/sec)	TIME Pk. RTD (ms)	AVERAGE RTD (N.m/sec)
Tony A.	17.40	2.004	0.76	1.85	2.004	0.08	0.17	1.384	73.9	524.7	108.3	53.3
Mike B.	28.80	2.004	0.89	2.25	2.004	0.21	0.61	1.833	51.6	210.9	157.8	28.2
Shawn C.	14.00	2.004	0.70	1.68	2.004	0.19	0.43	0.708	55.7	578.0	65.5	78.7
Nick C.	30.10	2.004	0.88	2.43	2.004	0.06	0.16	1.877	69.3	329.2	101.0	36.9
John C.	30.10	2.004	1.08	2.46	2.004	0.19	0.49	1.941	76.2	982.2	104.3	39.2
Jay D.	17.40	2.004	0.54	1.29	2.004	0.16	0.39	1.186	57.7	656.6	66.9	48.6
Ryan K.	32.10	2.004	1.08	3.41	2.004	0.14	0.68	1.738	58.5	634.7	98.3	33.6
Jay M.	30.80	2.004	0.83	2.15	2.004	0.06	0.12	1.189	60.8	518.2	106.3	51.1
Thoi N.	28.10	2.004	0.77	2.45	2.004	0.14	0.36	0.974	55.9	598.1	125.1	57.4
Mean	25.42	2.004	0.84	2.22	2.004	0.14	0.38	1.426	62.2	559.2	103.7	47.5
S.D.	7.03	.000	0.17	0.60	.000	0.06	0.20	0.442	8.7	216.0	28.0	15.3

	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	0.10	0.09
Mike B.	0.24	0.27
Shawn C.	0.27	0.26
Nick C.	0.06	0.06
John C.	0.17	0.20
Jay D.	0.30	0.30
Ryan K.	0.13	0.20
Jay M.	0.07	0.06
Thoi N.	0.19	0.15
Mean	0.17	0.18
S.D.	0.09	0.09

1 RM DATA

Ballistic training arm

Pre-Training

Subject:	Wt. (Kg.)	PT (N.m)	EMD (ms)	AG AEMG(mV)	AG PK. EMG (mV)	ANT AEMG(mV)	ANT PK. EMG (mV)	ANT/AG	ANT/AG PK	AG. Dur. (sec)	ANT. Dur. (sec)
Tony A.	15.76	60.95	7.40	.4778	1.4663	.1161	.4117	.243	.281	5.494	5.492
Mike B.	10.02	38.01	133.10	.5938	1.5154	.0901	.2527	.152	.167	2.660	2.564
Shawn C.	9.43	34.25	-33.40	.7843	1.8647	.0820	.1828	.105	.098	2.288	2.271
Nick C.	14.38	66.42	0.00	1.0690	2.6992	.1052	.2484	.098	.092	2.318	2.354
John C.	14.59	52.64	-18.70	.8456	2.5346	.0807	.1728	.095	.068	3.764	3.748
Jay D.	10.67	38.24	3.30	.5985	1.8024	.0877	.2454	.147	.136	1.849	1.794
Ryan K.	14.78	56.68	29.40	1.3685	3.2858	.1043	.3230	.076	.098	2.707	2.694
Jay M.	17.50	62.71	-8.00	.6965	1.5575	.0796	.2259	.114	.145	3.057	3.051
Thoi N.	14.02	45.62	28.00	.8328	3.3162	.0836	.2198	.100	.066	5.203	5.171
MEAN	13.46	50.61	15.68	.8074	2.2269	.0922	.2536	.126	.128	3.260	3.238
SD	2.78	11.98	48.41	.2730	.7475	.0131	.0736	.050	.067	1.301	1.307

Post-Training

Subject:	Wt. (Kg.)	PT (N.m)	EMD (ms)	AG AEMG(mV)	AG PK. EMG (mV)	ANT AEMG(mV)	ANT PK. EMG (mV)	ANT/AG	ANT/AG PK	AG. Dur. (sec)	ANT. Dur. (sec)
Tony A.	16.10	58.06	44.80	.6760	1.5776	.0782	.2487	.116	.158	3.226	3.146
Mike B.	12.55	47.43	22.70	.7545	1.7745	.1215	.3481	.161	.196	2.539	2.492
Shawn C.	10.05	36.40	14.10	.7411	1.6251	.0965	.2230	.130	.137	3.175	3.176
Nick C.	15.23	57.43	32.10	1.1812	3.3374	.1242	.3146	.105	.094	5.409	5.340
John C.	14.70	54.41	-8.70	.6289	2.2074	.0919	.2201	.146	.100	4.745	4.735
Jay D.	10.50	37.83	120.00	.7099	1.7929	.1151	.2844	.162	.159	3.422	3.474
Ryan K.	14.30	55.33	48.20	1.2304	3.3026	.0848	.2713	.069	.082	4.756	4.747
Jay M.	17.31	59.08	-10.00	.6677	1.7593	.0664	.1459	.099	.083	2.869	2.891
Thoi N.	14.12	48.21	69.60	.7538	2.1486	.1167	.3262	.155	.152	5.365	5.425
MEAN	13.87	50.46	36.98	.8159	2.1695	.0995	.2647	.127	.129	3.945	3.936
SD	2.43	8.60	40.60	.2253	.6858	.0208	.0630	.032	.041	1.117	1.122

1 RM DATA

Heavy Resistance training arm

Pre-Training

Subject:	Wt. (Kg.)	PT (N.m)	EMD (ms)	AG AEMG(mV)	AG PK. EMG (mV)	ANT AEMG(mV)	ANT PK. EMG (mV)	ANT/AG	ANT/AG PK	AG. Dur. (sec)	ANT. Dur. (sec)
Tony A.	15.76	60.95	7.40	.4873	2.1099	.1056	.3978	.217	.189	8.098	8.030
Mike B.	10.39	38.17	47.50	.7114	1.9030	.1246	.4431	.175	.233	2.973	2.959
Shawn C.	12.05	42.75	16.70	.6693	1.4163	.0972	.2680	.145	.189	2.263	2.214
Nick C.	16.70	66.42	-44.10	1.5650	4.2094	.1193	.3836	.076	.091	5.761	5.768
John C.	12.82	47.56	2.00	.9530	2.5346	.0621	.1515	.065	.060	2.878	2.901
Jay D.	11.99	42.06	24.70	.4894	1.0052	.0780	.1782	.159	.177	2.377	2.375
Ryan K.	13.37	51.06	10.00	1.0187	3.4120	.1135	.3580	.111	.105	2.960	2.969
Jay M.	18.22	61.51	20.70	.6318	1.6315	.0788	.2050	.125	.126	2.476	2.469
Thoi N.	12.72	43.33	-29.40	.5078	1.1540	.1008	.2819	.198	.244	2.543	2.536
MEAN	13.78	50.42	6.17	.7815	2.1529	.0978	.2964	.141	.157	3.592	3.580
SD	2.55	10.17	27.84	.3511	1.0697	.0210	.1046	.052	.065	1.997	1.983

Post-Training

Subject:	Wt. (Kg.)	PT (N.m)	EMD (ms)	AG AEMG(mV)	AG PK. EMG (mV)	ANT AEMG(mV)	ANT PK. EMG (mV)	ANT/AG	ANT/AG PK	AG. Dur. (sec)	ANT. Dur. (sec)
Tony A.	19.30	68.09	53.50	.7785	3.8068	.0681	.1996	.087	.052	3.602	3.599
Mike B.	16.58	61.66	10.70	1.1416	3.4568	.3970	1.0123	.348	.293	2.687	2.679
Shawn C.	17.00	58.63	16.70	.6687	1.8028	.1124	.3515	.168	.195	3.315	3.287
Nick C.	19.65	72.82	21.40	1.5820	3.9140	.1041	.3053	.066	.078	5.119	5.070
John C.	22.55	82.44	109.00	1.0841	2.9232	.1280	.3243	.118	.111	3.571	3.557
Jay D.	16.55	55.93	-10.70	.9984	2.4894	.1731	.4822	.173	.194	4.119	4.133
Ryan K.	15.98	61.37	34.80	1.0516	2.9666	.0997	.6548	.095	.221	4.134	4.272
Jay M.	21.71	71.92	16.10	.6274	1.7994	.0641	.2020	.102	.112	3.306	3.254
Thoi N.	19.51	62.53	44.10	.7377	2.3222	.0963	.2804	.131	.121	4.238	4.258
MEAN	18.76	66.15	32.84	.9633	2.8312	.1381	.4236	.143	.153	3.788	3.790
SD	2.38	8.40	34.31	.3006	.7938	.1023	.2628	.085	.077	.703	.713

EMG RATIOS

Ballistic training arm

Pre-Training

Ballistic/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	.87	.85	.42	.39	.48	.46
Mike B.	.75	.95	.66	.46	.88	.49
Shawn C.	.91	.91	.38	.44	.42	.49
Nick C.	.79	.81	.56	.38	.72	.47
John C.	.83	.76	.65	.41	.79	.54
Jay D.	.67	.84	.57	.56	.85	.66
Ryan K.	.77	1.17	.29	.40	.38	.34
Jay M.	1.43	2.22	.31	.29	.22	.13
Thoi N.	1.17	1.00	.55	.56	.47	.56
Mean	.91	1.06	.49	.43	.58	.46
S.D.	.24	.45	.14	.09	.23	.15

Post-Training

Ballistic/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	1.07	.84	.75	.65	.70	.78
Mike B.	1.05	.99	.85	.66	.82	.66
Shawn C.	1.10	.65	.47	.36	.43	.56
Nick C.	.82	.87	.95	.77	1.16	.89
John C.	.76	.93	.70	.90	.93	.97
Jay D.	.46	.44	.58	.41	1.27	.95
Ryan K.	.60	.55	.93	.69	1.55	1.26
Jay M.	.79	.82	.61	.46	.77	.56
Thoi N.	.78	.79	.70	.62	.91	.79
Mean	.82	.76	.73	.61	.95	.82
S.D.	.22	.18	.16	.17	.33	.22

EMG RATIOS

Heavy resistance training arm

Pre-Training

Ballistic/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	1.07	.97	.73	.96	.68	.99
Mike B.	.86	.54	.49	.51	.57	.96
Shawn C.	.80	.91	.62	.66	.77	.72
Nick C.	.72	.65	.65	.71	.91	1.08
John C.	1.00	.85	.58	.27	.58	.32
Jay D.	1.20	1.04	.42	.37	.35	.36
Ryan K.	.70	.63	.45	.13	.65	.20
Jay M.	1.07	1.20	.43	.34	.40	.29
Thoi N.	1.26	1.11	.71	.78	.56	.71
Mean	.96	.88	.56	.53	.61	.62
S.D.	.20	.23	.12	.27	.17	.34

Post-Training

Ballistic/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	.89	.86	.67	.66	.75	.77
Mike B.	.83	.79	.47	.30	.56	.37
Shawn C.	.88	.80	.46	.49	.52	.60
Nick C.	.93	.72	.98	.74	1.04	1.02
John C.	.79	1.09	.32	.26	.41	.24
Jay D.	1.21	1.08	.57	.52	.47	.48
Ryan K.	.97	.34	.57	.27	.58	.79
Jay M.	.70	.60	.65	.71	.92	1.18
Thoi N.	1.19	.68	.83	.54	.69	.79
Mean	.93	.77	.61	.50	.66	.69
S.D.	.17	.23	.20	.19	.21	.30

EMG RATIOS

Ballistic training arm

Pre-Training

Ballistic/1RM

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	.89	.66	.56	.32	.63	.48
Mike B.	1.15	1.28	1.00	.75	.86	.59
Shawn C.	.73	.70	1.07	1.27	1.46	1.81
Nick C.	.46	.43	.40	.31	.87	.71
John C.	.94	.76	.73	.77	.78	1.01
Jay D.	.65	.63	.88	.65	1.36	1.04
Ryan K.	.73	.93	.46	.39	.63	.42
Jay M.	1.05	1.75	.48	.63	.46	.36
Thoi N.	.59	.37	.63	.53	1.06	1.46
Mean	.80	.84	.69	.62	.90	.87
S.D.	.23	.44	.24	.30	.34	.50

Post-Training

Ballistic/1RM

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	1.02	1.04	1.05	.73	1.03	.70
Mike B.	1.17	1.24	.85	.71	.73	.57
Shawn C.	.85	.72	.97	.75	1.14	1.04
Nick C.	.62	.42	.68	.57	1.10	1.34
John C.	1.11	.83	.84	1.13	.76	1.36
Jay D.	.43	.39	.57	.43	1.31	1.10
Ryan K.	.49	.35	1.25	.66	2.55	1.88
Jay M.	.78	.68	.66	.60	.85	.88
Thoi N.	.65	.55	.66	.46	1.00	.84
Mean	.79	.69	.84	.67	1.16	1.08
S.D.	.27	.31	.22	.21	.55	.40

EMG RATIOS

Heavy resistance training arm

Pre-Training

Ballistic/1RM

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	1.24	.53	.83	.67	.66	1.26
Mike B.	.86	.78	.84	.55	.97	.70
Shawn C.	.81	.82	1.16	.96	1.43	1.17
Nick C.	.38	.33	.44	.34	1.15	1.02
John C.	.86	.67	1.32	1.00	1.54	1.49
Jay D.	.93	1.39	.64	.62	.69	.45
Ryan K.	.57	.35	.78	.71	1.37	2.03
Jay M.	.78	.84	.56	.42	.71	.50
Thoi N.	1.63	1.52	.92	.83	.56	.54
Mean	.90	.80	.83	.68	1.01	1.02
S.D.	.36	.42	.28	.23	.37	.53

Post-Training

Ballistic/1RM

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	.87	.42	.76	.57	.88	1.37
Mike B.	.65	.52	.25	.18	.39	.34
Shawn C.	.91	.75	.78	.59	.85	.79
Nick C.	.52	.45	.52	.38	1.01	.84
John C.	.78	.92	.47	.39	.60	.42
Jay D.	.65	.56	.54	.42	.82	.75
Ryan K.	1.00	.40	.78	.28	.78	.71
Jay M.	.93	.72	.60	.42	.64	.58
Thoi N.	1.24	.72	1.25	.70	1.00	.97
Mean	.84	.60	.66	.44	.78	.75
S.D.	.22	.18	.28	.16	.20	.30

EMG RATIOS

Ballistic training arm

Pre-Training

1RM/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	.98	1.27	.74	1.23	.76	.96
Mike B.	.65	.74	.66	.62	1.02	.83
Shawn C.	1.24	1.30	.36	.35	.29	.27
Nick C.	1.71	1.86	1.41	1.22	.82	.66
John C.	.88	1.01	.89	.54	1.01	.54
Jay D.	1.05	1.34	.65	.85	.62	.64
Ryan K.	1.06	1.25	.63	1.03	.60	.83
Jay M.	1.36	1.27	.65	.46	.48	.36
Thoi N.	1.99	2.74	.87	1.05	.44	.38
Mean	1.21	1.42	.76	.82	.67	.61
S.D.	.42	.58	.29	.33	.25	.24

Post-Training

1RM/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	1.05	.80	.71	.89	.67	1.11
Mike B.	.89	.80	1.00	.92	1.12	1.16
Shawn C.	1.29	.90	.49	.49	.38	.54
Nick C.	1.32	2.05	1.41	1.37	1.06	.67
John C.	.68	1.12	.83	.80	1.22	.71
Jay D.	1.06	1.12	1.03	.97	.97	.86
Ryan K.	1.22	1.57	.74	1.05	.61	.67
Jay M.	1.02	1.21	.93	.78	.91	.64
Thoi N.	1.19	1.43	1.07	1.34	.90	.94
Mean	1.08	1.22	.91	.96	.87	.81
S.D.	.20	.41	.26	.28	.27	.22

EMG RATIOS

Heavy resistance training arm

Pre-Training

1RM/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	.86	1.82	.89	1.42	1.03	.78
Mike B.	1.00	.69	.58	.94	.58	1.36
Shawn C.	.99	1.11	.53	.68	.54	.62
Nick C.	1.89	1.97	1.50	2.08	.79	1.05
John C.	1.16	1.26	.44	.27	.38	.21
Jay D.	1.29	.75	.65	.60	.51	.80
Ryan K.	1.22	1.82	.58	.18	.47	.10
Jay M.	1.36	1.43	.76	.83	.56	.58
Thoi N.	.77	.73	.77	.94	1.00	1.30
Mean	1.17	1.29	.75	.88	.65	.76
S.D.	.33	.51	.31	.58	.23	.44

Post-Training

1RM/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Tony A.	1.03	2.06	.88	1.16	.85	.56
Mike B.	1.29	1.54	1.85	1.67	1.43	1.09
Shawn C.	.96	1.07	.59	.82	.62	.76
Nick C.	1.80	1.61	1.86	1.96	1.04	1.22
John C.	1.00	1.19	.68	.67	.68	.56
Jay D.	1.85	1.92	1.06	1.24	.57	.64
Ryan K.	.97	.87	.73	.96	.75	1.11
Jay M.	.75	.84	1.09	1.70	1.44	2.04
Thoi N.	.96	.95	.67	.78	.69	.82
Mean	1.18	1.34	1.04	1.22	.90	.98
S.D.	.39	.46	.49	.46	.34	.47

ISOMETRIC EVOKED CONTRACTILE PROPERTIES

Ballistic training arm

Pre-training

Subjects	PT N.m	TPT ms	RT ms	MRTD N.m/s	ARTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP-HRT N.m.s	HRT ms	TPT + HRT ms	TWT/MVC
JAY D.	5.70	47.37	31.07	171.13	120.38	-103.22	0.61	0.31	36.57	83.93	0.12
JAY M.	13.68	60.15	39.61	329.32	227.39	-84.43	1.51	1.10	62.93	123.08	0.29
JOHN C.	7.56	66.58	35.57	215.07	113.55	-78.30	0.97	0.69	71.75	138.32	0.13
MIKE B.	8.65	56.84	34.91	232.12	152.25	-97.29	1.22	0.64	57.50	114.34	0.20
NICK C.	7.45	67.90	43.16	158.76	109.74	-80.18	0.89	0.55	56.12	124.03	0.11
RYAN K.	10.14	59.82	39.52	233.03	169.57	-111.55	1.23	0.75	54.26	114.08	0.16
SHAWN C.	9.99	65.32	45.31	195.97	152.88	-128.73	1.52	0.94	84.53	149.85	0.23
THOI N.	6.79	64.65	38.74	174.75	105.06	-94.42	0.86	0.53	51.20	115.85	0.14
TONY A.	10.35	58.76	39.05	239.85	176.07	-74.82	1.63	1.10	100.17	158.93	0.19
Mean	8.92	60.82	38.55	216.66	147.43	-94.77	1.16	0.73	63.89	124.71	0.17
SE	0.80	2.11	1.43	17.22	13.36	5.89	0.12	0.09	6.35	7.41	0.02

ISOMETRIC EVOKED CONTRACTILE PROPERTIES

Ballistic training arm

Post-training

Subjects	PT N.m	TPT ms	RT ms	MRTD N.m/s	ARTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP-HRT N.m.s	HRT ms	TPT + HRT ms	TWT/MVC
JAY D.	4.94	43.13	26.70	181.77	114.59	-56.17	0.65	0.35	58.30	101.42	0.11
JAY M.	15.33	65.06	45.45	319.72	235.70	-194.08	1.64	1.16	52.67	117.72	0.27
JOHN C.	10.47	62.07	42.25	239.92	168.68	-120.93	1.37	0.90	68.63	130.71	0.18
MIKE B.	7.90	57.17	36.90	222.98	138.12	-95.97	1.27	0.61	62.93	120.10	0.18
NICK C.	8.56	63.26	41.93	190.74	135.27	-98.53	0.96	0.63	53.40	116.66	0.13
RYAN K.	7.31	60.68	41.32	172.31	120.44	-110.78	0.76	0.47	41.06	101.73	0.12
SHAWN C.	9.64	60.42	41.65	221.95	159.52	-86.07	1.41	0.99	96.70	157.11	0.21
THOI N.	8.10	51.60	34.29	221.60	156.89	-125.99	0.90	0.55	51.53	103.14	0.16
TONY A.	10.94	59.16	40.25	247.71	184.89	-92.33	1.69	1.08	93.18	152.34	0.18
Mean	9.24	58.06	38.97	224.30	157.12	-108.98	1.18	0.75	64.27	122.33	0.17
SE	0.97	2.27	1.87	14.70	12.40	12.66	0.13	0.10	6.34	6.94	0.02

ISOMETRIC EVOKED CONTRACTILE PROPERTIES

Heavy Resistance training arm

Pre-training

Subjects	PT N.m	TPT ms	RT ms	MRTD N.m/s	ARTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP-HRT N.m.s	HRT ms	TPT + HRT ms	TWT/MVC
JAY D.	9.81	56.84	34.85	272.15	172.59	-93.47	1.27	0.79	71.55	128.39	0.22
JAY M.	11.48	59.03	42.03	246.64	194.52	-144.61	1.19	0.84	56.18	115.21	0.21
JOHN C.	5.75	68.63	45.11	122.22	83.72	-68.50	0.60	0.46	59.29	127.92	0.09
MIKE B.	8.38	64.66	35.77	240.52	129.55	-119.99	1.33	0.74	76.45	141.11	0.20
NICK C.	8.73	62.47	41.39	200.74	139.75	-86.08	1.16	0.67	58.23	120.70	0.12
RYAN K.	5.72	56.11	38.14	161.02	101.87	-104.30	0.62	0.31	37.52	93.64	0.11
SHAWN C.	7.34	68.63	44.04	165.62	106.95	-70.64	1.19	0.82	106.79	175.42	0.14
THOI N.	6.73	55.65	34.25	183.44	120.87	-96.98	0.78	0.48	49.36	105.00	0.14
TONY A.	10.22	57.77	38.42	252.95	176.89	-89.77	1.36	0.89	77.18	134.94	0.17
Mean	8.24	61.09	39.33	205.03	136.30	-97.15	1.06	0.67	65.84	126.93	0.16
SE	0.68	1.73	1.33	16.92	12.62	7.94	0.10	0.07	6.69	7.80	0.02

ISOMETRIC EVOKED CONTRACTILE PROPERTIES

Heavy Resistance training arm

Post-training

Subjects	PT N.m	TPT ms	RT ms	MRTD N.m/s	ARTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP-HRT N.m.s	HRT ms	TPT + HRT ms	TWT/MVC
JAY D.	9.50	63.86	39.68	222.21	148.70	-80.10	1.26	0.87	74.99	138.86	0.16
JAY M.	13.26	71.81	50.48	278.57	184.62	-147.19	1.76	1.21	64.99	136.80	0.22
JOHN C.	11.10	62.40	43.39	244.01	177.84	-109.93	1.31	0.92	66.25	128.65	0.15
MIKE B.	11.17	62.34	40.88	261.51	179.15	-109.39	1.45	0.94	65.12	127.46	0.22
NICK C.	9.52	67.18	46.23	185.04	141.69	-100.48	1.37	0.78	62.80	129.98	0.14
RYAN K.	5.07	58.63	40.56	137.35	86.51	-62.29	0.60	0.33	49.49	108.11	0.09
SHAWN C.	9.21	61.48	40.51	203.77	149.76	-72.56	1.53	0.99	102.28	163.77	0.17
THOI N.	11.87	49.81	32.83	342.38	238.38	-129.15	1.42	0.93	67.44	117.25	0.21
TONY A.	13.47	56.51	39.03	309.60	238.37	-96.32	1.98	1.45	101.96	158.46	0.18
Mean	10.46	61.56	41.51	242.71	171.67	-100.82	1.41	0.94	72.81	134.37	0.17
SE	0.85	2.09	1.64	21.22	15.95	9.01	0.13	0.10	5.96	5.95	0.01

MUSCLE FIBER DATA
(% of Fiber Types)

Ballistic training arm

Pre-training

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Tony A.	32.6				29.1	9.2	29.1	100.0
Mike B.	39.7				20.0	8.8	31.4	100.0
Shawn C.	37.2				24.1	5.0	33.6	100.0
Nick C.	34.7				33.3	10.7	21.2	100.0
John C.	19.2				38.5	12.6	29.6	100.0
Jay D.	37.3				32.4	12.0	18.3	100.0
Ryan K.	14.7				28.0	20.9	36.5	100.0
Jay M.	19.8				35.5	9.2	35.5	100.0
Thoi N.	22.0				17.8	19.5	40.7	100.0
MEAN	28.6	0.0	0.0	0.0	28.8	12.0	30.7	100.0
SD	9.5	0.0	0.0	0.0	7.0	5.1	7.2	0.0

	I	IIA	IIAB	IIB
	32.6	29.1	9.2	29.1
	39.7	20.0	8.8	31.4
	37.2	24.1	5.0	33.6
	34.7	33.3	10.7	21.2
	19.2	38.5	12.6	29.6
	37.3	32.4	12.0	18.3
	14.7	28.0	20.9	36.5
	19.8	35.5	9.2	35.5
	22.0	17.8	19.5	40.7
MEAN	28.6	28.8	12.0	30.7
SD	9.5	7.0	5.1	7.2

Post-Training

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Tony A.	23.0			0.2	36.0	14.8	26.0	100.0
Mike B.	34.0				14.7	9.9	41.4	100.0
Shawn C.	46.2				21.7	19.1	13.0	100.0
Nick C.	30.4				37.3	10.3	22.0	100.0
John C.	41.9	0.7		1.0	20.4	12.5	23.5	100.0
Jay D.	35.2			0.4	25.8	12.3	26.3	100.0
Ryan K.	32.2				36.4	4.2	27.2	100.0
Jay M.	29.1				30.9	15.2	24.8	100.0
Thoi N.	16.4				21.7	17.4	44.5	100.0
MEAN	32.0	0.1	0.0	0.2	27.2	12.8	27.6	100.0
SD	9.0	0.0	0.0	0.0	8.2	4.5	9.7	0.0

	I	IIA	IIAB	IIB
	23.2	36.0	14.8	26.0
	34.0	14.7	9.9	41.4
	46.2	21.7	19.1	13.0
	30.4	37.3	10.3	22.0
	43.6	20.4	12.5	23.5
	35.6	25.8	12.3	26.3
	32.2	36.4	4.2	27.2
	29.1	30.9	15.2	24.8
	16.4	21.7	17.4	44.5
MEAN	32.3	27.2	12.8	27.6
SD	9.3	8.2	4.5	9.7

MUSCLE FIBER DATA
(% of Fiber Types)

Heavy Resistance training arm

Pre-training

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Tony A.	29.0				32.5	6.0	32.5	100.0
Mike B.	39.7				20.0	8.8	31.4	100.0
Shawn C.	41.9				24.3	9.4	24.3	100.0
Nick C.	32.4				52.0	8.5	7.0	100.0
John C.	19.2				38.5	12.6	29.6	100.0
Jay D.	28.4				20.8	18.4	32.5	100.0
Ryan K.	14.7				28.0	20.9	36.5	100.0
Jay M.	19.8				35.5	9.2	35.5	100.0
Thoi N.	22.0				17.8	19.5	40.7	100.0
MEAN	27.5	0.0	0.0	0.0	29.9	12.6	30.0	100.0
SD	9.4	0.0	0.0	0.0	11.0	5.5	9.8	0.0

	I	IIA	IIAB	IIB
	29.0	32.5	6.0	32.5
	39.7	20.0	8.8	31.4
	41.9	24.3	9.4	24.3
	32.4	52.0	8.5	7.0
	19.2	38.5	12.6	29.6
	28.4	20.8	18.4	32.5
	14.7	28.0	20.9	36.5
	19.8	35.5	9.2	35.5
	22.0	17.8	19.5	40.7
MEAN	27.5	29.9	12.6	30.0
SD	9.4	11.0	5.5	9.8

Post-Training

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Tony A.	13.4				58.6	23.3	4.8	100.0
Mike B.	50.5				40.9	6.7	1.8	100.0
Shawn C.	42.9				38.9	17.2	1.1	100.0
Nick C.	22.2			0.7	36.4	25.3	15.3	100.0
John C.	23.7	3.1		1.3	38.8	20.7	12.4	100.0
Jay D.	36.3				23.9	19.9	19.1	100.0
Ryan K.	19.1				45.3	25.3	10.3	100.0
Jay M.	26.5				40.5	4.4	28.7	100.0
Thoi N.	19.9				47.9	23.8	8.4	100.0
MEAN	28.3	0.3	0.0	0.3	41.2	18.5	11.3	100.0
SD	12.3	0.0	0.0	0.0	9.3	7.8	8.8	0.0

	I	IIA	IIAB	IIB
	13.4	58.6	23.3	4.8
	50.5	40.9	6.7	1.8
	42.9	38.9	17.2	1.1
	23.0	36.4	25.3	15.3
	28.1	38.8	20.7	12.4
	37.1	23.9	19.9	19.1
	19.1	45.3	25.3	10.3
	26.5	40.5	4.4	28.7
	19.9	47.9	23.8	8.4
MEAN	28.9	41.2	18.5	11.3
SD	12.2	9.3	7.8	8.8

MUSCLE FIBER DATA

Heavy Resistance training arm

Pre-training

Number of fibers / Fiber type

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Tony A.	92				103	19	103	317
Mike B.	274				138	61	217	690
Shawn C.	272				158	61	158	649
Nick C.	301				483	79	65	928
John C.	169				338	111	260	878
Jay D.	262				192	170	300	924
Ryan K.	116				221	165	288	790
Jay M.	97				174	45	174	490
Thoi N.	53				43	47	98	241
SUM	1636.0	0.0	0.0	0.0	1850.0	758.0	1663.0	5907.0
MEAN	181.8	0.0	0.0	0.0	205.6	84.2	184.8	656.3
SD	95.9	0.0	0.0	0.0	132.1	53.5	86.6	257.1

Post-Training

Number of fibers / Fiber type

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Tony A.	104				455	181	37	777
Mike B.	578				468	77	21	1144
Shawn C.	280				254	112	7	653
Nick C.	208			7	340	237	143	935
John C.	248	32		14	407	217	130	1048
Jay D.	234			5	154	128	123	644
Ryan K.	104				247	138	56	545
Jay M.	132				202	22	143	499
Thoi N.	76				183	91	32	382
SUM	1964.0	32.0	0.0	26.0	2710.0	1203.0	692.0	6627.0
MEAN	218.2	32.0	0.0	8.7	301.1	133.7	76.9	736.3
SD	153.4	0.0	0.0	0.0	119.8	68.8	56.7	259.4

MUSCLE FIBER DATA

Ballistic training arm

Pre-training

Number of fibers / Fiber type

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Tony A.	141				126	40	126	433
Mike B.	274				138	61	217	690
Shawn C.	548				355	74	495	1472
Nick C.	278				267	86	170	801
John C.	169				338	111	260	878
Jay D.	224				195	72	110	601
Ryan K.	116				221	165	288	790
Jay M.	97				174	45	174	490
Thoi N.	53				43	47	98	241
SUM	1900.0	0.0	0.0	0.0	1857.0	701.0	1938.0	6396.0
MEAN	211.1	0.0	0.0	0.0	206.3	77.9	215.3	710.7
SD	148.3	0.0	0.0	0.0	101.4	39.6	123.5	350.2

Post-Training

Number of fibers / Fiber type

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Tony A.	352			3	552	226	399	1532
Mike B.	369				160	107	449	1085
Shawn C.	790				370	326	223	1709
Nick C.	378				464	128	274	1244
John C.	412	7		10	201	123	231	984
Jay D.	83			1	61	29	62	236
Ryan K.	713				806	93	602	2214
Jay M.	138				147	72	118	475
Thoi N.	49				65	52	133	299
SUM	3284.0	7.0	0.0	14.0	2826.0	1156.0	2491.0	9778.0
MEAN	364.9	7.0	0.0	4.7	314.0	128.4	276.8	1086.4
SD	258.7	0.0	0.0	0.0	253.7	93.0	175.8	671.8

MUSCLE FIBER DATA

Ballistic training arm

Pre-training

	I		IIA		IIB	
Subjects	CSA	SD	CSA	SD	CSA	SD
Tony A.	4381	759	5113	1179	4679	1492
Mike B.	3777	900	4395	687	5683	1411
Shawn C.	3457	530	4848	906	4810	535
Nick C.	3802	374	4462	704	3919	738
John C.	4924	917	6906	1473	6767	1964
Jay D.	3995	671	5061	827	4770	738
Ryan K.	5349	422	5814	878	5591	750
Jay M.	4531	782	5449	1215	6261	997
Thoi N.	4244	668	4988	1251	4753	683

MEAN	4273.3	669.2	5226.2	1013.3	5248.1	1034.2
SD	599.1	194.6	769.1	274.5	894.1	480.4
SEM	154.9	50.6	184.5	78.9	245.2	130.7

Post-Training

	I		IIA		IIB	
Subjects	CSA	SD	CSA	SD	CSA	SD
Tony A.	4312	623	5327	732	5187	805
Mike B.	4134	565	6729	999	6470	1407
Shawn C.	4036	434	5472	600	5200	664
Nick C.	3812	591	4984	611	3939	480
John C.	4034	573	6373	1192	5949	1060
Jay D.	4298	486	5460	830	4742	676
Ryan K.	3731	432	4804	743	4522	548
Jay M.	3423	559	5106	1259	6238	661
Thoi N.	4863	1190	6671	1540	6379	1541

MEAN	4071.4	605.9	5658.4	945.1	5402.9	871.3
SD	410.2	229.3	737.9	325.3	903.5	380.5
SEM	97.9	44.5	207.2	89.6	253.7	103.3

FIBSCASD.XLS

MUSCLE FIBER DATA

Heavy Resistance training arm

Pre-training

	I		IIA		IIB	
Subjects	CSA	SD	CSA	SD	CSA	SD
Tony A.	4789	937	5364	635	5081	870
Mike B.	3777	900	4395	687	5683	1411
Shawn C.	3632	696	5510	889	4557	659
Nick C.	3826	434	4810	916	4204	535
John C.	4924	917	6906	1473	6767	1964
Jay D.	4134	1118	5103	1057	4449	1048
Ryan K.	5349	422	5814	878	5591	750
Jay M.	4531	782	5449	1215	6261	997
Thoi N.	4244	668	4988	1251	4753	683

MEAN	4356.2	763.8	5371.0	1000.1	5260.7	990.8
SD	584.1	233.8	712.7	274.2	874.5	448.9
SEM	160.6	61.9	162.6	73.7	241.4	107.9

Post-Training

	I		IIA		IIB	
Subjects	CSA	SD	CSA	SD	CSA	SD
Tony A.	6502	959	7690	1430	8820	1095
Mike B.	6693	883	9744	1304	8458	907
Shawn C.	5201	656	7595	978	7477	1141
Nick C.	4362	547	5867	1046	5863	1116
John C.	5031	685	7528	1174	6609	1612
Jay D.	4196	593	6289	1102	5643	574
Ryan K.	5341	991	6120	1252	5666	668
Jay M.	5208	947	8819	1844	10138	2072
Thoi N.	7645	1088	9442	1921	8254	1708

MEAN	5575.4	816.6	7677.1	1339.0	7436.4	1210.3
SD	1139.8	197.3	1429.5	337.3	1598.3	496.2
SEM	304.7	58.2	369.4	87.3	441.8	130.4

FIBSCASD.XLS

DPX DATA
Training group

	Whole arm scan Lean (grams)				Regional box scan Lean (grams)			
	Ballistic		Heavy Resistance		Ballistic		Heavy Resistance	
Subjects	pre	post	pre	post	pre	post	pre	post
Thoi N.	2748.2	2995.7	2838.9	3191.9	878.8	961.9	932.3	1123.6
Jay M.	3480.0	3176.0	3420.0	3366.0	1247.0	1104.0	1262.0	1278.0
Shawn C.	2843.0	2920.0	2831.0	2948.0	810.4	808.4	799.2	832.4
Jay D.	3058.7	2910.8	3295.4	3226.1	926.4	933.7	970.9	1081.6
Tony A.	3001.5	3058.5	3138.6	3257.1	987.5	921.6	975.6	1047.4
Mike B.	2845.9	3033.1	2995.4	3322.7	960.8	1066.7	961.8	1099.3
Nick C.	3911.7	4363.3	4289.6	5077.6	1480.4	1628.5	1483.1	1886.7
Ryan K.	3574.0	3576.0	3613.0	3582.0	1101.0	1047.0	1020.0	1034.0
John C.	3181.0	3414.0	3077.0	3403.0	882.0	895.1	868.1	966.7
Mean	3182.7	3271.9	3277.7	3486.0	1030.5	1040.8	1030.3	1150.0
SD	393.5	467.2	459.4	621.1	213.7	239.1	211.9	301.1

	Body Mass (Kilograms)		Body Fat (%)		Lean mass (Kilograms)	
Subjects	Pre	Post	Pre	Post	Pre	Post
Thoi N.	60.51	63.62	9.2	9.5	52.44	55.02
Jay M.	70.58	70.87	10.7	10.6	60.42	60.79
Shawn C.	66.75	68.50	11.2	10.5	56.46	58.43
Jay D.	77.00	73.13	18.8	14.6	59.40	59.52
Tony A.	78.45	75.39	14.3	12.0	64.44	63.57
Mike B.	69.04	73.64	14.7	15.1	56.08	59.59
Nick C.	88.90	93.85	14.8	15.5	72.04	75.44
Ryan K.	79.11	75.07	11.1	9.0	67.51	65.42
John C.	73.48	76.74	11.2	11.2	62.30	65.17
Mean	73.8	74.5	12.9	12.0	61.2	62.6
SD	8.3	8.3	3.0	2.5	6.1	5.9

Training Subjects Physical Characteristics

Subjects	Age yrs.	Height cm.	Scale Weight, kg pre	Scale Weight, kg post	Body Mass, kg. pre	Body Mass, kg. post	Lean body mass, kg. pre	Lean body mass, kg. post	% Body Fat pre	% Body Fat post
Tony A.	21.0	177.0	78.0	75.5	78.5	75.4	64.4	63.6	14.3	12.0
Mike B.	21.0	177.0	70.5	74.8	69.0	73.6	56.1	59.6	14.7	15.1
Shawn C.	21.0	179.0	71.5	72.3	66.8	68.5	56.5	58.4	11.2	10.5
Nick C.	22.0	186.0	98.4	95.5	88.9	93.9	72.0	75.4	14.8	15.5
John C.	20.0	183.0	74.5	77.0	73.5	76.7	62.3	65.2	11.2	11.2
Jay D.	22.0	176.0	77.9	72.9	77.0	73.1	59.4	59.5	18.8	14.6
Ryan K.	20.0	191.0	82.8	88.1	79.11	75.07	67.5	65.4	11.1	9.0
Jay M.	23.0	173.0	73.0	72.8	70.6	70.9	60.4	60.8	10.7	10.6
Thoi N.	21.0	160.0	60.2	64.2	60.5	63.6	52.4	55.0	9.2	9.5
Tony R. *	20.0	176.0	57.7	58.8						
Mean	21.1	177.8	74.5	75.2	73.8	74.5	61.2	62.6	12.9	12.0
S.D.	1.0	8.3	11.4	10.5	8.3	8.3	6.1	5.9	3.0	2.5

* Data not collected because of arm injury during training

APPENDIX B

Spreadsheets of Control Group Raw Data

BALLISTIC ACTIONS

Control subjects

Pre-training

	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	MRTD (N.m.s-1)	Peak Power (watts)
Adam R.	208.0	12.46	121.82	15.22	88.3	416.8	104.34
Bill R.	202.0	12.4	130.39	31.7	106.3	716.0	244.64
Chris P.	189.9	14.09	142.16	16.23	80.3	480.2	132.89
Danial V.	200.7	13.17	125.91	17.01	68.2	501.59	145.75
Ian J.	182.6	14.84	149.71	19.65	76.2	630.8	212.50
Jonathan	204.7	13.11	133.10	15.22	85.6	385.4	122.30
Matt B.	230.1	12.55	113.15	19.08	133.0	329.0	157.86
Mike J.	206.7	11.59	103.69	23.75	86.3	663.0	173.78
Tim B.	223.4	11.68	110.99	19.99	99.7	505.0	152.66
Tim H.	212.7	11.33	109.75	16.81	75.6	545.7	99.97
Mean	206.08	12.72	124.07	19.47	89.95	517.35	154.67
S.D.	14.08	1.12	15.00	5.03	18.89	124.33	45.88

Post-training

	MT (ms)	Peak VEL. (rad.s-1)	Peak ACC. (rad.s-2)	Peak Torque (N.m)	Time to PT (ms)	MRTD (N.m.s-1)	Peak Power (watts)
Adam R.	219.4	11.24	122.96	15.80	80.90	471	88.20
Bill R.	208.0	12.03	117.48	34.49	86.90	964	238.32
Chris P.	182.6	14.65	136.76	17.82	78.90	493	153.68
Danial V.	210.0	12.72	106.76	15.85	93.00	304	122.23
Ian J.	183.3	15.11	140.53	18.55	129.10	506	205.98
Jonathan	202.6	13.65	130.11	15.32	123.10	313	138.13
Matt B.	204.7	12.88	118.49	21.92	90.30	629	175.93
Mike J.	212.7	12.25	106.85	25.87	96.30	661	210.70
Tim B.	230.1	11.07	93.64	20.28	121.10	426	148.74
Tim H.	199.3	9.84	91.04	15.27	72.20	452	83.88
Mean	205.3	12.54	116.46	20.12	97.18	522	157
S.D.	14.7	1.63	16.93	6.09	20.16	193	52

BALLDATA.XLS

BALLISTIC ELECTROMYOGRAPHY

Control Subjects

Pre-training

Subjects	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	ANT/AG AEMG	ANT/AG Pk. EMG
Adam R.	30.8	270	.5494	1.335	262.2	.0936	0.219	0.170	0.164
Bill R.	52.8	278.2	.7604	2.248	319	.0563	0.106	0.146	0.094
Chris P.	28.8	242	.2888	0.566	248	.0476	0.096	0.165	0.170
Danial V.	39.5	256.8	.7255	1.637	245.4	.0947	0.175	0.131	0.107
Ian J.	39.5	240.8	.9743	1.833	252.1	.0969	0.228	0.099	0.125
Jonathan A.	36.1	262.2	.5029	0.991	266.9	.0924	0.474	0.184	0.478
Matt B.	19.4	287	.4471	1.062	278.2	.0496	0.123	0.111	0.115
Mike J.	35.4	270.2	.5905	1.041	274.9	.0611	0.099	0.104	0.095
Tim B.	39.5	294.3	.5756	1.138	268.2	.0537	0.093	0.093	0.082
Tim H.	29.4	268.2	.5619	1.112	275.5	.0658	0.163	0.117	0.147
Mean	35.12	266.97	.5976	1.2964	269.04	.0712	.1776	0.132	0.158
S.D.	8.88	17.42	.1873	.485	21.07	.0207	.1156	0.032	0.116

BALLISTIC ELECTROMYOGRAPHY

Control Subjects

Post-training

Subjects	EMD (ms)	AG Duration (ms)	AG AEMG (mv)	AG Pk. EMG (mv)	ANT Duration (ms)	ANT AEMG (mv)	ANT Pk. EMG (mv)	ANT/AG AEMG	ANT/AG Pk. EMG
Adam R.	28.8	272.2	.5158	1.259	273.5	.0751	0.149	0.15	0.12
Bill R.	51.5	277.6	1.2983	2.830	302.3	.0647	0.153	0.10	0.11
Chris P.	42.1	246.2	.4177	0.864	280.2	.0647	0.141	0.15	0.16
Danial V.	27.4	260.2	.9420	2.074	249.4	.1062	0.221	0.11	0.11
Ian J.	33.41	238.1	.7407	1.447	232.7	.0751	0.129	0.10	0.09
Jonathan A.	41.5	274.9	.3476	0.911	266.9	.0647	0.131	0.19	0.14
Matt B.	36.1	268.9	.4590	0.844	258.9	.0944	0.181	0.21	0.21
Mike J.	21.4	260.2	.5515	1.455	244.1	.0542	0.094	0.10	0.06
Tim B.	62.2	329.7	.6300	1.442	291.6	.0579	0.104	0.09	0.07
Tim H.	22.7	246.1	.5231	0.865	234.1	.0759	0.252	0.15	0.29
Mean	36.71	267.41	.6426	1.3991	263.37	.0733	.1555	0.13	0.14
S.D.	12.96	25.67	.2866	.6367	23.79	.0162	.0498	0.04	0.07

Control Subjects Pre -Training

	Maximum Voluntary Contraction										
Subject	EMD	AG Duration	AG IEMG	AG Pk. EMG	ANT Duration	ANT IEMG	ANT Pk. EMG	TPT	PT	Pk. RTD	TIME Pk. RTD
Adam R.	33.4	2	.4276	1.054	2	.0971	0.371	1.22	29.86	303	71.6
Brad R.	21.4	2	.7604	1.962	2	.0991	0.228	1.32	82.71	609	105.7
Chris P.	38.8	2	.2296	0.682	2	.0437	0.250	0.1518	31.6	604	46.1
Danial V.	29.4	2	.7222	1.723	2	.1864	0.831	1.3991	36.9	542	44.2
Ian J.	41.5	2	.7358	1.744	2	.1338	0.321	1.2085	45.5	639	67.5
Jonathan A.	28.8	2	.4082	1.024	2	.0998	0.251	1.054	36.23	292	80.9
Matt B.	29.4	2	.4266	1.910	2	.0486	0.136	0.9116	50.73	541	51.5
Mike J.	27.4	2	.5397	1.368	2	.1028	0.554	1.7208	58.67	562	80.9
Tim B.	38.8	2	.9345	2.370	2	.0829	0.208	1.9703	58.19	568	76.9
Tim H.	34.1	2	.6125	1.321	2	.0871	0.199	1.056	41.81	469	50.8
Mean	32.30	2.00	.5797	1.52	2.00	.0981	0.33	1.20	47.22	512.90	67.61
S.D.	6.20	0.00	.212	0.52	0.00	.0406	0.21	0.49	16.08	122.61	19.60

	ANT/AG AEMG	ANT/AG Pk. EMG
Adam R.	0.227	0.352
Bill R.	0.130	0.116
Chris P.	0.191	0.367
Danial V.	0.258	0.482
Ian J.	0.182	0.184
Jonathan A.	0.245	0.245
Matt B.	0.114	0.071
Mike J.	0.190	0.405
Tim B.	0.089	0.088
Tim H.	0.142	0.151
Mean	0.177	0.246
S.D.	0.057	0.146

Control Subjects Post -Training

	Maximum Voluntary Contraction										
Subject	**EMD**	**AG Duration**	**AG IEMG**	**AG Pk. EMG**	**ANT Duration**	**ANT IEMG**	**ANT Pk. EMG**	**TPT**	**PT**	**Pk. RTD**	**TIME Pk. RTD**
Adam R.	20.7	2.004	.6814	1.973	2	.1338	0.350	.673	41.77	268.0	113.7
Brad R.	50.8	2.004	1.0381	2.235	2	.0974	0.228	1.922	76.07	761.3	60.2
Chris P.	28.1	2.004	.2874	0.927	2	.0795	0.308	1.333	41.44	618.0	60.9
Danial V.	30.1	2.004	.6059	1.168	2	.1769	0.360	1.065	41.33	648.0	34.8
Ian J.	18.7	2.004	.6521	1.763	2	.1284	0.288	.42	45.72	383.0	78.3
Jonathan A.	28.8	2.004	.3548	1.164	2	.092	0.216	1.253	40.61	277.6	91.2
Matt B.	29.4	2.004	.4337	1.000	2	.0879	0.189	.589	54.72	586.0	68.2
Mike J.	34.1	2.004	.6021	1.406	2	.1041	0.319	1.625	60.26	636.0	71.9
Tim B.	31.8	2.004	.856	2.000	2	.1048	0.267	.945	58.92	625.0	49.8
Tim H.	24.7	2.004	.6099	1.593	2	.1104	0.273	.777	43.4	480.0	62.3
Mean	29.72	2.00	.6122	1.52	2.00	.1115	0.28	1.06	50.42	528.29	69.13
S.D.	8.82	0.00	.2239	0.46	0.00	.0285	0.06	0.48	11.79	168.32	21.89

	ANT/AG AEMG	**ANT/AG Pk. EMG**
Adam R.	0.196	0.177
Bill R.	0.094	0.102
Chris P.	0.277	0.332
Danial V.	0.292	0.309
Ian J.	0.197	0.164
Jonathan A.	0.259	0.186
Matt B.	0.203	0.189
Mike J.	0.173	0.227
Tim B.	0.122	0.134
Tim H.	0.181	0.171
Mean	0.199	0.199
S.D.	0.063	0.072

1 RM DATA
Control Subjects

Pre-Training

Subject:	Wt. (Kg.)	PT (N.m)	EMD (ms)	AG AEMG(mV)	AG PK. EMG (mV)	ANT AEMG(mV)	ANT PK. EMG (mV)	ANT/AG	ANT/AG PK.	AG. Dur. (sec)	ANT. Dur. (sec)
Matt B.	13.28	49.03	38.10	.6208	1.6200	.0534	.1430	.086	.088	3.220	3.156
Adam R.	10.45	36.89	72.90	.5351	1.4830	.0825	.2020	.154	.136	2.478	2.443
Bill R.	20.25	68.60	0.00	.9301	2.5000	.1805	.4640	.194	.186	4.298	4.230
Tim B.	12.80	46.16	76.90	.7488	2.3546	.0701	.1837	.094	.078	4.313	4.297
Chris P.	10.42	39.36	14.00	.2995	.6783	.0965	.2587	.322	.381	3.226	3.216
Ian J.	12.65	42.33	55.50	.8420	1.9330	.1148	.2649	.136	.137	2.157	2.183
Jon A.	10.90	36.25	34.80	.4602	1.0681	.0721	.1810	.157	.169	2.374	2.364
Danial V.	10.21	33.47	22.10	.6994	2.0526	.1629	.4877	.233	.238	5.447	5.480
Tim H.	8.54	34.99	30.10	.6287	1.7353	.0955	.3066	.152	.177	4.745	4.743
Mike J.	14.12	44.77	18.00	.5667	1.4610	.0771	.3012	.136	.206	2.105	2.172
MEAN	12.36	43.19	36.24	.6331	1.6886	.1005	.2793	.166	.180	3.436	3.428
SD	3.25	10.31	25.28	.1841	.5579	.0413	.1168	.070	.086	1.193	1.187

1 RM DATA

Control Subjects

Post-Training

Subject:	Wt. (Kg.)	PT (N.m)	EMD (ms)	AG AEMG(mV)	AG PK. EMG (mV)	ANT AEMG(mV)	ANT PK. EMG (mV)	ANT/AG	ANT/AG PK.	AG. Dur. (sec)	ANT. Dur. (sec)
Matt B.	14.50	52.17	12.70	.5851	2.2970	.0783	.2215	.134	.096	2.646	2.691
Adam R.	9.91	34.03	46.80	.7774	2.0756	.0947	.2603	.122	.125	4.639	4.585
Bill R.	19.60	69.39	-24.70	1.0994	2.3646	.1445	.3277	.131	.139	2.440	2.419
Tim B.	12.87	46.55	26.10	.7798	2.5432	.1060	.3638	.136	.143	4.478	4.477
Chris P.	11.95	43.05	50.80	.3086	.8538	.0895	.2329	.290	.273	2.773	2.773
Ian J.	12.86	42.61	58.90	.8185	2.4960	.1164	.3026	.142	.121	1.810	1.784
Jon A.	12.34	40.61	60.20	.4569	1.3144	.0788	.2202	.172	.168	2.937	2.856
Danial V.	9.33	31.47	18.10	.6648	1.6609	.1951	.4266	.293	.257	3.008	2.983
Tim H.	10.39	40.33	103.00	.6459	1.8083	.1323	.3434	.205	.190	2.573	2.410
Mike J.	15.88	58.24	80.30	.5803	1.5538	.0992	.3533	.171	.227	3.386	3.413
MEAN	12.96	45.84	43.22	.6717	1.8968	.1135	.3052	.180	.174	3.069	3.039
SD	3.08	11.41	36.55	.2165	.5574	.0359	.0699	.064	.061	.886	.893

EMG RATIOS

Control subjects

Pre-Training

Ballistic/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Adam R.	1.28	1.27	.96	.59	.75	.47
Bill R.	1.00	1.15	.57	.47	.57	.41
Chris P.	1.26	.83	1.09	.39	.87	.46
Danial V.	1.00	.95	.51	.21	.51	.22
Ian J.	1.32	1.05	.72	.71	.55	.68
Jonathan A.	1.23	.97	.93	1.89	.75	1.95
Matt B.	1.05	.56	1.02	.90	.97	1.62
Mike J.	1.09	.76	.59	.18	.54	.24
Tim B.	.62	.48	.65	.45	1.05	.93
Tim H.	.92	.84	.76	.82	.82	.97
Mean	1.08	.89	.78	.66	.74	.79
S.D.	.21	.25	.21	.49	.19	.59

Post-Training

Ballistic/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Adam R.	.76	.64	.56	.43	.74	.67
Bill R.	1.25	1.27	.66	.67	.53	.53
Chris P.	1.45	.93	.81	.46	.56	.49
Danial V.	1.55	1.78	.60	.61	.39	.34
Ian J.	1.14	.82	.59	.45	.52	.55
Jonathan A.	.98	.78	.70	.60	.72	.77
Matt B.	1.06	.84	1.07	.96	1.01	1.14
Mike J.	.92	1.03	.52	.30	.57	.29
Tim B.	.74	.72	.55	.39	.75	.54
Tim H.	.86	.54	.69	.92	.80	1.70
Mean	1.07	.94	.68	.58	.66	.70
S.D.	.28	.36	.16	.22	.18	.42

EMG RATIOS

Control subjects

Pre-Training

Ballistic/1RM

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Adam R.	1.03	.90	1.13	1.08	1.10	1.20
Bill R.	.82	.90	.31	.23	.38	.25
Chris P.	.96	.84	.49	.37	.51	.45
Danial V.	1.04	.80	.58	.36	.56	.45
Ian J.	1.16	.95	.84	.86	.73	.91
Jonathan A.	1.09	.93	1.28	2.62	1.17	2.82
Matt B.	.72	.66	.93	.86	1.29	1.31
Mike J.	1.04	.71	.79	.33	.76	.46
Tim B.	.77	.48	.77	.51	1.00	1.05
Tim H.	.89	.64	.69	.53	.77	.83
Mean	.95	.78	.78	.77	.83	.97
S.D.	.15	.15	.29	.70	.30	.74

Post-Training

Ballistic/1RM

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Adam R.	.66	.61	.79	.57	1.20	.94
Bill R.	1.18	1.20	.45	.47	.38	.39
Chris P.	1.35	1.01	.72	.60	.53	.60
Danial V.	1.42	1.25	.54	.52	.38	.41
Ian J.	.90	.58	.65	.43	.71	.74
Jonathan A.	.76	.69	.82	.59	1.08	.86
Matt B.	.78	.37	1.21	.82	1.54	2.23
Mike J.	.95	.94	.55	.27	.58	.29
Tim B.	.81	.57	.55	.28	.68	.50
Tim H.	.81	.48	.57	.73	.71	1.53
Mean	.96	.77	.68	.53	.78	.85
S.D.	.26	.31	.22	.18	.38	.60

EMG RATIOS

Control subjects

Pre-Training

1RM/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Adam R.	1.25	1.41	.85	.54	.68	.39
Bill R.	1.22	1.27	1.82	2.04	1.49	1.60
Chris P.	1.30	.99	2.21	1.03	1.69	1.04
Danial V.	.97	1.19	.87	.59	.90	.49
Ian J.	1.14	1.11	.86	.83	.75	.74
Jonathan A.	1.13	1.04	.72	.72	.64	.69
Matt B.	1.46	.85	1.10	1.05	.76	1.24
Mike J.	1.05	1.07	.75	.54	.71	.51
Tim B.	.80	.99	.85	.88	1.05	.89
Tim H.	1.03	1.31	1.10	1.54	1.07	1.17
Mean	1.14	1.12	1.11	.98	.97	.88
S.D.	.19	.17	.50	.48	.36	.39

Post-Training

1RM/MVC

Subjects	AG AEMG	AG Pk. EMG	ANT AEMG	ANT Pk. EMG	ANT/AG AEMG	ANT/AG Pk. EMG
Adam R.	1.14	1.05	.71	.74	.62	.71
Bill R.	1.06	1.06	1.48	1.44	1.40	1.36
Chris P.	1.07	.92	1.13	.76	1.05	.82
Danial V.	1.10	1.42	1.11	1.18	1.01	.83
Ian J.	1.26	1.42	.91	1.05	.72	.74
Jonathan A.	1.29	1.13	.86	1.02	.67	.90
Matt B.	1.35	2.30	.89	1.17	.66	.51
Mike J.	.96	1.10	.95	1.11	.99	1.00
Tim B.	.91	1.27	1.01	1.36	1.11	1.07
Tim H.	1.06	1.14	1.20	1.26	1.13	1.11
Mean	1.12	1.28	1.02	1.11	.94	.91
S.D.	.14	.39	.22	.23	.26	.24

ISOMETRIC EVOKED CONTRACTILE PROPERTIES

Control subjects

Pre-training

Subjects	PT N.m	TPT ms	RT ms	MRTD N.m/s	ARTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP-HRT N.m.s	HRT ms	TPT + HRT ms	TWT/MVC
Mike J.	11.33	62.47	42.27	257.05	181.30	-114.34	1.6	1.09	85.46	147.93	0.17
Tim B.	8.79	60.09	42.07	227.73	146.36	-102.96	1.16	0.48	53.4	113.48	0.15
Tim H.	7.22	84.66	36.57	207.22	85.28	-102.33	0.67	0.61	48.76	133.42	0.17
Daniel V.	6.96	60.95	36.7	193.19	114.27	-102.03	0.85	0.48	46.77	107.72	0.17
Adam R.	4.84	55.71	36.37	128.14	86.84	-68.14	0.6	0.32	53.2	108.91	0.13
Bill R.	11.13	71.55	45.78	217.33	155.62	-121.54	1.37	0.93	60.22	131.77	0.13
Chris P.	8.05	60.88	37.1	230.23	132.29	-100.07	0.93	0.57	47.96	108.84	0.22
Ian J.	8.2	67.11	44.25	170.42	122.22	-153.38	1.76	0.83	81.29	148.4	0.18
Matt B.	8.81	59.29	37.8	216.88	148.59	-86.14	1.18	0.86	89.93	149.22	0.17
Jonathan A.	6.65	66.97	44.91	152.69	99.26	-80.24	0.93	0.56	70.62	137.59	0.18
Mean	8.20	64.97	40.38	200.09	127.20	-103.12	1.10	0.67	63.76	128.73	0.17
SE	0.63	2.63	1.21	12.43	9.97	7.48	0.12	0.08	5.28	5.53	0.01

ISOMETRIC EVOKED CONTRACTILE PROPERTIES

Control subjects

Post-training

Subjects	PT N.m	TPT ms	RT ms	MRTD N.m/s	ARTD N.m/s	MRTR N.m/s	IMP N.m.s	IMP-HRT N.m.s	HRT ms	TPT + HRT ms	TWT/MVC
Mike J.	14.64	64.52	44.72	338.21	226.89	-139.64	1.98	1.33	75.12	139.65	0.24
Tim B.	10.13	61.94	42.66	283.27	163.54	-103.82	1.29	0.52	60.22	122.16	0.17
Tim H.	6.97	57.37	37.76	170.71	121.42	-90.2	0.75	0.76	56.97	114.34	0.16
Daniel V.	6.57	63.46	38.89	165.0	103.52	-88.54	0.69	0.49	53.79	117.26	0.16
Adam R.	6.95	57.7	38.22	166.49	120.42	-50.78	0.85	0.49	52.07	109.77	0.17
Bill R.	10.34	60.88	40.21	268.88	169.84	-55.29	1.38	0.87	66.58	127.46	0.13
Chris P.	9.13	67.71	40.88	275.78	134.85	-119.69	0.87	0.69	48.63	116.33	0.21
Ian J.	7.71	61.81	41.2	173.51	124.78	-120.05	1.48	0.77	86.05	147.86	0.17
Matt B.	8.92	62.01	40.74	216.2	143.85	-99.6	1.04	0.64	54.59	116.6	0.16
Jonathan A.	8.48	65.91	45.45	169.88	128.69	-99.85	1.33	0.83	84.73	150.64	0.21
Mean	8.98	62.33	41.07	222.79	143.78	-96.75	1.17	0.74	63.88	126.21	0.18
SE	0.75	1.04	0.81	20.11	11.21	8.77	0.13	0.08	4.32	4.65	0.01

MUSCLE FIBER DATA
(% of Fiber Types)

Control Subjects

Pre-training

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Matt B.	35.2				39.3	8.1	17.4	100.0
Tim B.	28.6				16.3	22.5	32.6	100.0
Ian J.	37.8		0.9		35.6	16.3	9.4	100.0
Chris P.	34.0				32.6	9.8	23.7	100.0
Bill R.	42.0				34.0	10.9	13.0	100.0
Jon A.	43.5				30.0	8.1	18.4	100.0
MEAN	35.5	0.0	0.9	0.0	31.6	13.5	19.2	100.0
SD	5.0	0.0	0.0	0.0	8.9	5.9	9.2	0.0

	I	IIA	IIAB	IIB
	35.2	39.3	8.1	17.4
	28.6	16.3	22.5	32.6
	37.8	35.6	16.3	9.4
	34.0	32.6	9.8	23.7
	42.0	34.0	10.9	13.0
	43.5	30.0	8.1	18.4
MEAN	36.8	31.3	12.6	19.1
SD	5.5	8.0	5.7	8.2

Post-Training

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Matt B.	34.4				40.4	13.3	11.9	100.0
Tim B.	24.4				13.9	21.5	40.2	100.0
Ian J.	34.5				29.6	9.2	26.7	100.0
Chris P.	32.0				23.8	13.7	30.5	100.0
Bill R.	43.1				26.7	4.8	25.4	100.0
Jon A.	43.2				30.1	7.7	19.1	100.0
MEAN	35.3	0.0	0.0	0.0	27.4	11.7	25.6	100.0
SD	7.1	0.0	0.0	0.0	8.7	5.9	9.7	0.0

	I	IIA	IIAB	IIB
	34.4	40.4	13.3	11.9
	24.4	13.9	21.5	40.2
	34.5	29.6	9.2	26.7
	32.0	23.8	13.7	30.5
	43.1	26.7	4.8	25.4
	43.2	30.1	7.7	19.1
MEAN	35.3	27.4	11.7	25.6
SD	7.1	8.7	5.9	9.7

MUSCLE FIBER DATA

Control Subjects

Pre-training

Number of fibers / Fiber type

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Matt B.	1061				1186	244	526	3017
Tim B.	170				97	134	194	595
Ian J.	287		7		270	124	71	759
Chris P.	218				209	63	152	642
Bill R.	374				303	97	116	890
Jon A.	289				199	54	122	664
SUM	2399	0	7	0	2264	716	1181	6567
MEAN	400	0	7	0	377	119	197	1095
SD	331	0	0	0	402	69	166	948

Post-Training

Number of fibers / Fiber type

Subjects	I	IC	IIC	IIAC	IIA	IIAB	IIB	TOTAL
Matt B.	328				385	127	113	953
Tim B.	161				92	142	265	660
Ian J.	274				235	73	212	794
Chris P.	248				185	106	237	776
Bill R.	134				83	15	79	311
Jon A.	857				597	152	380	1986
SUM	2002	0	0	0	1577	615	1286	5480
MEAN	334	0	0	0	263	103	214	913
SD	266	0	0	0	197	51	109	568

MUSCLE FIBER DATA

Control Subjects

Pre-training

	I		IIA		IIB	
Subjects	CSA	SD	CSA	SD	CSA	SD
Matt B.	4162	850	5103	938	5134	1391
Tim B.	3518	755	5328	1371	5693	1529
Ian J.	4418	629	6090	809	6217	660
Chris P.	3847	659	6180	858	6289	809
Bill R.	3764	464	5166	517	5918	890
Jon A.	3579	401	5777	989	5560	987

MEAN	3881	626	5607	914	5802	1044
SD	348	170	473	278	433	342
SEM	111.2	52.8	166.7	75.8	138.6	113.1

Post-Training

	I		IIA		IIB	
Subjects	CSA	SD	CSA	SD	CSA	SD
Matt B.	3761	944	4904	1269	4518	1348
Tim B.	3473	801	5150	1234	5035	882
Ian J.	2546	425	3219	708	3475	688
Chris P.	3663	415	6677	972	6210	982
Bill R.	3919	823	6061	1009	6310	971
Jon A.	3867	718	5696	784	6078	1055

MEAN	3538	688	5285	996	5271	988
SD	511	220	1195	228	1137	217
SEM	143.9	72.8	351.2	71.3	379.0	58.2

FIBSCASD.XLS

DPX DATA

Control group

	Whole arm scan Lean (grams)				Regional box scan Lean (grams)			
	Left arm		Right arm		Left arm		Right arm	
Subjects	pre	post	pre	post	pre	post	pre	post
Matt B.	3461.0	3174.7	3457.6	3339.9	896.9	872.1	908.8	863.9
Bill R.	3662.9	3586.9	3921.3	3927.4	1248.3	1239.6	1343.9	1356.3
Adam R.	2464.0	2401.0	2697.0	2611.0	718.3	697.7	747.3	766.2
Mike J.	3159.0	3162.0	3165.0	3171.5	946.7	950.5	941.9	941.2
Tim B.	3382.6	3081.2	3444.8	3161.9	1055.0	1018.5	1074.0	1030.1
Tim H.	2825.5	2879.5	2909.5	2992.8	960.1	986.2	956.3	989.1
Chris P.	2921.3	2943.9	2837.8	2811.8	886.9	882.7	768.9	762.7
Mean	3125.2	3032.7	3204.7	3145.2	958.9	949.6	963.0	958.5
SD	415.9	359.8	431.3	422.4	163.3	165.4	202.1	203.7

	Body Mass (Kilograms)		Body Fat (%)		Lean mass (Kilograms)	
Subjects	Pre	Post	Pre	Post	Pre	Post
Matt B.	82.00	79.30	12.8	11.8	68.61	67.11
Bill R.	93.45	94.53	21.4	21.2	70.21	71.09
Adam R.	66.26	67.75	12.9	13.0	55.12	56.27
Mike J.	80.29	80.70	19.0	20.1	61.97	61.42
Tim B.	82.88	79.85	12.5	12.9	69.50	66.69
Tim H.	68.23	71.93	11.5	14.2	57.71	58.92
Ian J	65.67	67.05	9.5	11.8	56.93	56.62
Chris P.	70.89	70.90	19.5	20.1	54.45	54.02
Mean	76.21	76.50	14.9	15.6	61.81	61.52
SD	9.96	9.10	4.4	4.1	6.71	6.14

Control Subjects Physical Characteristics

	Age	Height	Scale Weight, kg		Body Mass, kg.		Lean body mass, kg.		% Body Fat	
Subjects	yrs.	cm.	pre	post	pre	post	pre	post	pre	post
Matt B.	21.0	182.5	83.7	81.4	82.0	79.3	68.6	67.1	12.8	11.8
Adam R.	20.0	177.5	67.1	68.6	66.3	67.8	55.1	56.3	12.9	13.0
Bill R.	20.0	188.0	96.5	98.2	93.5	94.5	70.2	71.1	21.4	21.2
Tim B.	23.0	187.0	85.0	80.8	82.9	79.9	69.5	66.7	12.5	12.9
Chris P.	21.0	170.0	72.1	71.8	70.9	70.9	54.5	54.0	19.5	20.1
Ian J.	20.0	168.0	64.6	67.8	65.7	67.1	56.9	56.6	9.5	11.8
Jonathan A.*	20.0	175.0	73.6	77.2						
Danial V. *	21.0	165.0	69.9	71.3						
Tim H.	21.0	181.5	69.9	73.1	68.2	71.9	57.7	58.9	11.5	14.2
Mike J.	20.0	179.0	80.0	81.5	80.3	80.7	62.0	61.4	19.0	20.1
Mean	20.7	177.4	76.2	77.2	76.2	76.5	61.8	61.5	14.9	15.6
S.D.	0.9	7.8	9.9	9.0	10.0	9.1	6.7	6.1	4.4	4.1

* Missing data due to corrupted data collection files (optical disk damaged)

APPENDIX C

Reproducibility Method Errors

Table 1. Reproducibility of Ballistic Action Testing

Measurements	Method error (%)	p=
Kinetic & Kinematic Measures		
Movement Time	3.9	.8301
Peak Velocity	4.3	.4911
Peak Accleration	5.4	*.0286*
Time to Peak Torque	23.6	.5816
Peak Torque	5.8	.2391
Peak RTD	21.7	.9309
Peak Power	8.9	.7670
Electromyography		
Electromechanical Delay	26.8	.7916
AG. AEMG	24.4	.5265
ANT AEMG	21.2	.7636
ANT/AG EMG	24.3	.3680
AG AEMG/MVC	19.8	.9510
ANT AEMG/ MVC	11.3	.0596
(ANT AG AEMG)/MVC	12.7	.0765
AG AEMG/1 RM	21.4	.9156
ANT AEMG/1 RM	23.7	.2482
(ANT/ AG AEMG)/1 RM	14.0	.3447

MEBALL3.XLS

Table 2. Reproducibility of Maximum Voluntary Contraction

Measurements	Method error (%)	p=
Kinetic Measures		
Peak Torque	7.5	.0816
Time to Peak Torque	41.0	.5137
Peak RTD	15.0	.6703
Time to Peak RTD	25.7	.8512
Electromyography		
Electromechanical Delay	32.0	.5757
AG. AEMG	16.2	.4714
ANT AEMG	13.5	.0635
ANT/AG EMG	16.4	.1351

Table 3. Reproducibility of One Repetition Maximum

Measurements	Method error (%)	p=
Kinetic Measures		
Weight lifted	5.6	.1095
Peak Torque	7.4	.1040
Electromyography		
Electromechanical Delay	73.3	.6048
AG. AEMG	10.0	.2201
ANT AEMG	31.9	.5350
ANT/AG EMG	17.6	.3510
AG AEMG/MVC	26.1	.5168
ANT AEMG/ MVC	26.3	.5018
(ANT/ AG AEMG)/MVC	17.7	.6279

Table 4. Reproducibility of Contractile Properties

Measurements	Method error (%)	p=
Twitch Peak Torque	11.2	.1017
Time to Peak Twitch Torque	11.0	.4234
Rise Time	5.0	.4663
MRTD	12.7	.0931
ARTD	10.0	.0226
MRTR	20.7	.4978
Impulse	14.5	.4192
Impulse to HRT	14.9	.1920
1/2 Relaxtation time (HRT)	15.6	.9801
TPT + HRT	7.9	.5779

Table 5. Reproducibility of Body Composition

Measurements	Method error (%)	p=
Whole Body Mass	2.1	.7257
Whole Body Lean Mass	1.6	.5641
Whole Body Fat	2.8	.1323
Whole Arm Lean Mass	3.0	.1062
Regional Arm lean Mass	1.8	.4726

Table 6. Reproducibility of Fiber Composition & Area

Measurements	Method error (%)	p=
Fiber Type Percentage		
Type I %	3.8	.1025
Type IIa %	9.8	.0699
Type IIb %	25.0	.1060
Fiber Area		
Type I	15.0	.3346
Type IIa	17.2	.5759
Type IIb	15.2	.3240

APPENDIX D

Anova Tables from Training Subjects

TRAINING GROUP STATISTICS

Ballistic (PT)

Summary of all Effects; design: (ballpt.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.58014	8	4.788967	.121140	.736782
2	1	62.22580	8	7.221509	8.616732	**.018841**
12	1	.06334	8	7.019730	.009023	.926661

Descriptive Statistics (ballpt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	21.25000	17.54000	22.88000	1.714738
BALPOST	9	23.96333	18.59000	29.67000	3.763167
HVPRE	9	21.58778	17.01000	25.44000	2.622393
HVPOST	9	24.13333	18.93000	31.07000	3.960126

Ballistic (TPT)

Summary of all Effects; design: (balltpt.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	102.347	8	604.9576	.169180	.691639
2	1	675.134	8	409.6242	1.648178	.235140
12	1	1081.314	8	544.0705	1.987451	.196278

Descriptive Statistics (balltpt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	98.8444	70.90000	157.2000	27.77126
BALPOST	9	101.1444	87.60000	127.7000	16.39498
HVPRE	9	113.1778	78.90000	164.5000	27.88260
HVPOST	9	93.5556	69.60000	121.1000	18.58878

Ballistic (RTD)

Summary of all Effects; design: (ballrtd.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	20928.45	8	27799.32	.752840	.410849
2	1	62333.45	8	19079.32	3.267069	.108303
12	1	7.11	8	27350.99	.000260	.987530

Descriptive Statistics (ballrtd.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	547.7778	446.0000	785.000	104.7995
BALPOST	9	630.1111	383.0000	1027.000	213.7723
HVPRE	9	498.6667	319.0000	708.000	125.4572
HVPOST	9	582.7778	406.0000	774.000	115.6069

Ballistic (Pk. Power)

Summary of all Effects; design: (balltpw.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	1523167.	8	2539252.	.59985	.460910
2	1	48611108	8	2618665.	18.56332	**.002586**
12	1	1788906.	8	1391562.	1.28554	.289703

Descriptive Statistics (balltpw.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	162.9206	135.3328	204.9714	20.08041
BALPOST	9	211.2643	157.5159	265.4122	38.45043
HVPRE	9	163.5218	123.4471	196.4891	24.24119
HVPOST	9	196.3030	133.9191	251.0481	39.20720

Ballistic (MT)

Summary of all Effects; design: (cnbagemg.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	212.6736	8	114.4380	1.858418	.209934
2	1	796.1803	8	148.7809	5.351361	**.049434**
12	1	86.1803	8	75.7547	1.137624	.317282

Descriptive Statistics (ballmt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	203.3111	184.6000	232.7000	15.30241
BALPOST	9	197.0000	180.6000	209.3000	8.90786
HVPRE	9	211.2667	194.6000	233.4000	11.29834
HVPOST	9	198.7667	165.2000	226.7000	19.09771

Ballistic (Pk. Velocity)

Summary of all Effects; design: (ballvel.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	506.25	8	1656.125	.30568	.595448
2	1	39534.70	8	2550.194	15.50262	**.004312**
12	1	812.25	8	987.750	.82232	.390997

Descriptive Statistics (ballvel.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	12.59546	11.72861	13.14233	.448638
BALPOST	9	13.91803	12.61873	16.31883	1.293697
HVPRE	9	12.63036	11.95550	14.43387	.781169
HVPOST	9	13.62132	12.18240	16.26647	1.267261

Ballistic (Pk. Acc.)

Summary of all Effects; design: (ballacc.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	166410.	8	366124.0	.454517	.519199
2	1	1989228.	8	841933.9	2.362689	.162823
12	1	299136.	8	573883.8	.521249	.490871

Descriptive Statistics (ballacc.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	126.8575	107.1108	143.8326	9.96032
BALPOST	9	131.8809	111.9279	160.2387	17.98300
HVPRE	9	121.3023	105.4528	136.6767	9.11503
HVPOST	9	132.6896	109.2925	182.1425	21.08758

MVC (PT)

Summary of all Effects; design: (mvaganpk.sta)
1-TRAIN, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	191.1767	8	23.98342	7.97120	**.022379**
2	1	182.4300	8	11.19324	16.29823	**.003751**
12	1	118.1569	8	12.65273	9.33846	**.015680**

Tukey HSD test; variable Var.1 (mvaganpk.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} 53.06556	{2} 53.94444	{3} 54.05111	{4} 62.17667
1	1	{1}		.950899	.933073	**.002902**
1	2	{2}	.950899		.999906	**.005292**
2	1	{3}	.933073	.999906		**.005711**
2	2	{4}	**.002902**	**.005292**	**.005711**	

Descriptive Statistics (mvcpt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	53.06556	43.21000	67.73000	8.946699
BALPOST	9	53.94444	43.93000	66.05000	7.747361
HVPRE	9	54.05111	41.48000	70.19000	9.031603
HVPOST	9	62.17667	51.64000	76.16000	8.733748

MVC (TPT)

Summary of all Effects; design: (mvctpt.sta)
1-TRAIN, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.732707	8	.107325	6.826998	**.030993**
2	1	.011856	8	.282484	.041969	.842795
12	1	.351471	8	.187028	1.879238	.207644

Descriptive Statistics (mvctpt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	1.103956	.521600	1.892100	.448723
BALPOST	9	.942633	.351100	1.950200	.569613
HVPRE	9	1.191667	.128400	1.723500	.493818
HVPOST	9	1.425578	.708300	1.940900	.442396

MVC (RTD)

Summary of all Effects; design: (mvcrtd.sta)
1-TRAIN, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	205.30	8	20140.16	.010194	.922064
2	1	7810.73	8	39768.64	.196404	.669379
12	1	33426.20	8	9259.25	3.610032	.093967

Descriptive Statistics (mvcrtd.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	534.4744	210.4100	727.3000	164.3243
BALPOST	9	624.8767	500.7000	846.4000	107.3826
HVPRE	9	590.6411	324.3500	828.6000	138.0112
HVPOST	9	559.1578	210.8500	982.2000	215.9625

MVC (TRTD)

Summary of all Effects; design: (mvctrtd.sta)
1-TRAIN, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	285.610	8	1165.373	.245080	.633870
2	1	8587.111	8	2185.271	3.929540	*.082753*
12	1	449.440	8	695.573	.646144	.444721

Descriptive Statistics (mvctrtd.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	67.2000	46.20000	123.8000	22.96427
BALPOST	9	105.1556	66.90000	164.5000	28.64294
HVPRE	9	79.9000	41.50000	254.2000	67.52848
HVPOST	9	103.7222	65.50000	157.8000	27.97985

MVC (ARTD)

Summary of all Effects; design: (mvcartd.sta)
1-TRAIN, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	372.158	8	3505.253	.106172	.752905
2	1	6.002	8	4042.271	.001485	.970206
12	1	6327.246	8	2561.440	2.470191	.154667

Descriptive Statistics (mvcartd.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	54.71386	33.45489	106.9594	23.20500
BALPOST	9	80.41188	29.92507	140.6437	47.06608
HVPRE	9	74.79806	31.20940	323.0530	93.68302
HVPOST	9	47.46675	28.18008	78.6531	15.25946

1 RM (PT)

Summary of all Effects; design: (1rmpt.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	540.5625	8	19.19324	28.16421	**.000722**
2	1	546.3127	8	42.90990	12.73162	**.007313**
12	1	567.3924	8	11.36003	49.94638	**.000105**

Tukey HSD test; variable Var.1 (1rmpt.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} 50.61333	{2} 50.46444	{3} 50.42333	{4} 66.15444
1	1	{1}		.999700	.999378	**.000253**
1	2	{2}	.999700		.999994	**.000251**
2	1	{3}	.999378	.999994		**.000251**
2	2	{4}	**.000253**	**.000251**	**.000251**	

Descriptive Statistics (1rmpt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	50.61333	34.25000	66.42000	11.98214
BALPOST	9	50.46444	36.40000	59.08000	8.59803
HVPRE	9	50.42333	38.17000	66.42000	10.17047
HVPOST	9	66.15444	55.93000	82.44000	8.39658

BALLISTIC (AG AEMG)

Summary of all Effects; design: (ballag.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.046550	8	.023085	2.016493	.193373
2	1	.050483	8	.009210	5.481191	**.047327**
12	1	.054081	8	.023910	2.261858	.171005

Descriptive Statistics (ballag.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.619950	.386190	.997474	.199291
BALPOST	9	.617327	.308442	.885430	.164739
HVPRE	9	.614350	.455211	.826531	.129555
HVPOST	9	.766763	.585593	1.049153	.154218

BALLISTIC (ANT AEMG)

Summary of all Effects; design: (ballant.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.000305	8	.000214	1.423962	.266937
2	1	.000581	8	.000199	2.926153	.125522
12	1	.001128	8	.000330	3.417581	.101684

Descriptive Statistics (ballant.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.062188	.038486	.089809	.019141
BALPOST	9	.081416	.043792	.105998	.019277
HVPRE	9	.079199	.043945	.112455	.024724
HVPOST	9	.076040	.038333	.120063	.026692

BALLISTIC (ANT/AG EMG)

Summary of all Effects; design: (balantag.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.000728	8	.001065 .	683513	.432345
2	1	.000027	8	.000831	.032651	.861100
12	1	.006970	8	.000979	7.121963	.028419

Tukey HSD test; variable Var.1 (balantag.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} .1115210	{2} .1376148	{3} .1303594	{4} .1007936
1	1	{1}		.352693	.600429	.883568
1	2	{2}	.352693		.958758	.135146
2	1	{3}	.600429	.958758		.262522
2	2	{4}	.883568	.135146	.262522	

Descriptive Statistics (balantag.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.111521	.048002	.199328	.051475
BALPOST	9	.137615	.084386	.211952	.039105
HVPRE	9	.130359	.087409	.208384	.041256
HVPOST	9	.100794	.065461	.143070	.036010

MVC (AG AEMG)

Summary of all Effects; design: (mvcag.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.001028	8	.016534	.06217	.809384
2	1	.111874	8	.008328	13.43354	**.006354**
12	1	.037498	8	.012793	2.93110	.125247

Descriptive Statistics (mvcag.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.713519	.418663	1.296707	.286125
BALPOST	9	.760462	.575399	1.008782	.156336
HVPRE	9	.659657	.379780	.833633	.163454
HVPOST	9	.835697	.539371	1.082934	.174349

MVC (ANT AEMG)

Summary of all Effects; design: (mvcant.sta)
1-TRAIN, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.002087	8	.001765	1.182854	.308454
2	1	.001439	8	.000925	1.555453	.247605
12	1	.000382	8	.000223	1.709278	.227401

Descriptive Statistics (mvcant.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.134235	.074633 .	230988	.047224
BALPOST	9	.115079	.071507	.198810 .	034928
HVPRE	9	.142952	.079540	.214222	.045257
HVPOST	9	.136820	.055858	.214980	.059692

MVC (AG/ANT EMG)

Summary of all Effects; design: (mvcagant.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.001659	8	.006259	.265071	.620577
2	1	.023333	8	.002696	8.654346	**.018657**
12	1	.000035	8	.000643	.054255	.821666

Descriptive Statistics (mvcagant.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.209047	.094346	.366334	.093991
BALPOST	9	.160099	.099060	.345516	.075117
HVPRE	9	.224594	.095965	.314211	.067171
HVPOST	9	.171707	.063573 .	303118	.087738

1 RM (AG AEMG)

Summary of all Effects; design: (1rmag.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	332.1227	8	540.3819	.614607	.455641
2	1	814.8107	8	221.4061	3.680165	*.091344*
12	1	675.3919	8	70.6848	9.554982	**.014864**

Tukey HSD test; variable Var.1 (1rmag.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1}	{2}	{3}	{4}
			.8074216	.8159436	.7815414	.9633187
1	1	{1}		.996250	.911675	**.018331**
1	2	{2}	.996250		.821099	**.024505**
2	1	{3}	.911675	.821099		**.007862**
2	2	{4}	**.018331**	**.024505**	**.007862**	

Descriptive Statistics (1rmag.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.807422	.477765	1.368507	.272977
BALPOST	9	.815944	.628944	1.230413	.225348
HVPRE	9	.781541	.487305	1.565041	.351126
HVPOST	9	.963319	.627363	1.582028	.300610

1 RM (ANT AEMG)

Summary of all Effects; design: (1rmant.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	43.98745	8	25.99233	1.692325	.229512
2	1	51.14933	8	31.90862	1.602994	.241101
12	1	24.48736	8	18.28395	1.339282	.280544

Descriptive Statistics (1rmagpk.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.092153	.079553	.116139	.013149
BALPOST	9	.099498	.066390	.124247	.020816
HVPRE	9	.097766	.062103	.124579	.020982
HVPOST	9	.138100	.064116	.397021	.102332

1 RM (AG/ANT EMG)

Summary of all Effects; design: (1rmagant.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	4371.51	8	76448.51	.057182	.817018
2	1	11.22	8	87428.33	.000128	.991240
12	1	14387.04	8	19422.20	.740752	.414469

Descriptive Statistics (1rmagant.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	8.840104	4.113722	13.11522	2.644713
BALPOST	9	8.451448	6.165736	14.50211	2.686729
HVPRE	9	8.219893	4.615644	15.34579	3.714487
HVPOST	9	8.630877	2.875390	15.19628	3.630646

BALLISTIC/MVC RATIO (AG EMG)

Summary of all Effects; design: (blmvag.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.014722	8	.016276	.904504	.369421
2	1	.007429	8	.011117	.668256	.437327
12	1	.001790	8	.005648	.316997	.588845

Descriptive Statistics (blmvag.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.454128	.336754	.713826	.120309
BALPOST	9	.411293	.230645	.547387	.108149
HVPRE	9	.480468	.347320	.626729	.102025
HVPOST	9	.465842	.351264	.603914	.085554

BALLISTIC/MVC RATIO (ANT EMG)

Summary of all Effects; design: (blmvant2.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.003553	8	.024734	.143661	.714530
2	1	.188051	8	.026336	7.140473	**.028267**
12	1	.082707	8	.010324	8.010783	**.022139**

Tukey HSD test; variable Var.1 (blmvant2.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} .4874563	{2} .7278684	{3} .5634489	{4} .6121358
1	1	{1}		**.004648**	.436589	.116508
1	2	{2}	**.004648**		**.036321**	.151091
2	1	{3}	.436589	**.036321**		.745126
2	2	{4}	.116508	.151091	.745126	

Descriptive Statistics (blmvant.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.487456	.290677	.657057	.139743
BALPOST	9	.727868	.471184	.950287	.160831
HVPRE	9	.563449	.418974	.731146	.121687
HVPOST	9	.612136	.321085	.975608	.198863

BALLISTIC/MVC RATIO (ANT/AG EMG)

Summary of all Effects; design: (blmvagat.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.144495	8	.087748	1.646703	.235331
2	1	.408715	8	.058147	7.029010	**.029200**
12	1	.225987	8	.034701	6.512361	**.034072**

Tukey HSD test; variable Var.1 (blmvagat.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} .5759619	{2} .9475251	{3} .6077139	{4} .6623563
1	1	{1}		**.012376**	.982727	.762484
1	2	{2}	**.012376**		**.019974**	**.047036**
2	1	{3}	.982727	**.019974**		.922147
2	2	{4}	.762484	**.047036**	.922147	

Descriptive Statistics (blmvagat.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.575962	.219294	.878497	.234745
BALPOST	9	.947525	.429535	1.553521	.334794
HVPRE	9	.607714	.349549	.910846	.172979
HVPOST	9	.662356	.408247	1.044191	.212033

1 RM/MVC RATIO (AG EMG)

Summary of all Effects; design: (rmmvag.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.007729	8	.152400	.050713	.827474
2	1	.034458	8	.068013	.506638	.496827
12	1	.043434	8	.045742	.949542	.358376

Descriptive Statistics (rmmvag.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	1.212170	.648386	1.989225	.420142
BALPOST	9	1.080824	.682258	1.324966	.203832
HVPRE	9	1.172005	.771671	1.888225	.332555
HVPOST	9	1.179598	.754145	1.850994	.390869

1 RM/MVC RATIO (ANT EMG)

Summary of all Effects; design: (rmmvant.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.029984	8	.051404	.583290	.466950
2	1	.453778	8	.063308	7.167791	**.028044**
12	1	.050026	8	.030656	1.631872	.237267

Descriptive Statistics (rmmvant.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.761869	.355132	1.409420	.288450
BALPOST	9	.911858	.485620	1.406883	.262096
HVPRE	9	.745034	.439008	1.499554	.314623
HVPOST	9	1.044132	.589619	1.863757	.490991

1 RM/MVC RATIO (ANT/AG EMG)

Summary of all Effects; design: (rmmvanag.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.000072	8	.081420	.000886	.976988
2	1	.450535	8	.053363	8.442883	**.019720**
12	1	.004417	8	.047101	.093785	.767237

Descriptive Statistics (rmmvanag.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.670288	.285521	1.016603	.253662
BALPOST	9	.871873	.377049	1.222347	.270570
HVPRE	9	.650964	.377760	1.025710	.233422
HVPOST	9	.896858	.572034	1.443492	.336552

BALL/1 RM RATIO (AG EMG)

Summary of all Effects; design: (blrmag.sta)
1-ARM, 2-TIME

	df	MS	df	MS		
	Effect	Effect	Error	Error	F	p-level
1	1	.046789	8	.117819	.397126	.546152
2	1	.008892	8	.018809	.472730	.511172
12	1	.005274	8	.037009	.142506	.715620

Descriptive Statistics (blrmag.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.799259	.459752	1.153531	.226440
BALPOST	9	.792034	.434508	1.173486	.267599
HVPRE	9	.895569	.380767	1.627592	.362867
HVPOST	9	.839929	.518912	1.240201	.217316

BALL/1 RM RATIO (ANT EMG)

Summary of all Effects; design: (blrmant.sta)
1-ARM, 2-TIME

	df	MS	df	MS		
	Effect	Effect	Error	Error	F	p-level
1	1	.002705	8	.047153	.057372	.816721
2	1	.001128	8	.080298	.014049	.908571
12	1	.224210	8	.044423	5.047206	*.054858*

Descriptive Statistics (blrmant.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.689637	.399360	1.070971	.244057
BALPOST	9	.836277	.567831	1.249326	.222800
HVPRE	9	.830136	.436713	1.320927	.278841
HVPOST	9	.661104	.254664	1.246356	.278213

BALL/1 RM RATIO (ANT/AG EMG)

Summary of all Effects; design: (blrmagat.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.174694	8	.078571	2.223402	.174271
2	1	.001568	8	.144855	.010828	.919686
12	1	.551717	8	.183850	3.000915	.121454

Descriptive Statistics (blrmagat.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.901620	.459528	1.461131	.337209
BALPOST	9	1.162414	.727737	2.550485	.552994
HVPRE	9	1.009891	.562832	1.535206	.373739
HVPOST	9	.775500	.392837	1.008771	.200191

Evoked contractile property (PT)

Summary of all Effects; design: (ecppt.sta)
1-GROUP, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.64320	8	5.609860	.11466	.743620
2	1	14.54660	8	3.173631	4.58358	*.064683*
12	1	8.17198	8	.554996	14.72440	**.004967**

Tukey HSD test; variable Var.1 (ecppt.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} 8.923778	{2} 9.242222	{3} 8.238222	{4} 10.46244
1	1	{1}		.802092	.280977	**.010206**
1	2	{2}	.802092		.081275	**.034271**
2	1	{3}	.280977	.081275		**.001179**
2	2	{4}	**.010206**	**.034271**	**.001179**	

Descriptive Statistics (ecppt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.	Standard Error
BALPRE	9	8.92378	5.702000	13.67800	2.404832	.801611
BALPOST	9	9.24222	4.942000	15.33400	2.904241	.968080
HVPRE	9	8.23822	5.716000	11.48200	2.026059	.675353
HVPOST	9	10.46244	5.072000	13.47000	2.554683	.851561

Evoked contractile property (TPT)

Summary of all Effects; design: (ecptpt.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	31.87355	8	36.73438	.867676	.378852
2	1	11.79922	8	28.33032	.416488	.536760
12	1	23.51927	8	7.96186	2.953990	.123987

Descriptive Statistics (ecptpt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.	Standard Error
BALLPRE	9	60.82156	47.36800	67.90400	6.331622	2.110541
BALPOST	9	58.06000	43.12600	65.05600	6.812404	2.270801
HVPRE	9	61.08689	55.64800	68.63400	5.197976	1.732659
HVPOST	9	61.55844	49.81200	71.81400	6.279345	2.093115

Evoked contractile property (RT)

Summary of all Effects; design: (ecprt.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	24.85421	8	13.43910	1.849396	.210937
2	1	15.22508	8	10.58195	1.438778	.264654
12	1	6.95166	8	5.96549	1.165313	.311834

Descriptive Statistics (ecprt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.	Standard Error
BALPRE	9	38.54956	31.07000	45.31400	4.292356	1.430785
BALPOST	9	38.97133	26.69800	45.44600	5.619364	1.873121
HVPRE	9	39.33249	34.25000	45.11200	3.998870	1.332957
HVPOST	9	41.51200	32.83000	50.48000	4.916616	1.638872

Evoked contractile property (MRTD)

Summary of all Effects; design: (ecpmrtd.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	103.409	8	2578.381	.040106	.846271
2	1	4620.963	8	1975.587	2.339033	.164695
12	1	2030.794	8	822.285	2.469695	.154703

Descriptive Statistics (ecpmrtd.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.	Standard Error
BALPRE	9	216.6647	158.7620	329.3220	51.65949	17.21983
BALPOST	9	224.3024	172.3100	319.7220	44.08737	14.69579
HVPRE	9	205.0329	122.2180	272.1520	50.77433	16.92478
HVPOST	9	242.7136	137.3460	342.3760	63.65196	21.21732

Evoked contractile property (ARTD)

Summary of all Effects; design: (ecpartd.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	26.189	8	1322.685	.019800	.891577
2	1	4568.640	8	1472.548	3.102540	.116198
12	1	1483.336	8	325.043	4.563509	*.065157*

Descriptive Statistics (ecpartd.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.	Standard Error
BALPRE	9	147.4321	105.0613	227.3906	40.08102	13.36034
BALPOST	9	157.1246	114.5944	235.7046	37.21275	12.40425
HVPRE	9	136.2999	83.7194	194.5244	37.85107	12.61702
HVPOST	9	171.6685	86.5116	238.3763	47.85315	15.95105

Evoked contractile property (MRTR)

Summary of all Effects; design: (ecpmrtr.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	75.1747	8	328.0977	.229123	.644984
2	1	719.6879	8	930.6541	.773314	.404833
12	1	249.5663	8	484.6674	.514923	.493433

Descriptive Statistics (ecpmrtr.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.	Standard Error
BALPRE	9	-94.773	-128.726	-74.8240	17.68244	5.89415
BALPOST	9	-108.981	-194.082	-56.1660	37.9931	12.66437
HVPRE	9	-97.148	-144.608	-68.498	23.82067	7.94022
HVPOST	9	-100.825	-147.194	-62.2940	27.02340	9.00780

Evoked contractile property (TTI)

Summary of all Effects; design: (ecpmrtr.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	337.334	8	965.6470	.34934	.570807
2	1	3214.890	8	550.5675	5.83923	**.042083**
12	1	2423.921	8	132.8086	18.25123	**.002716**

Tukey HSD test; variable Var.1 (ecpmrtr.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} 1.159778	{2} 1.184667	{3} 1.056889	{4} 1.410000
1	1	{1}		.966189	.302464	**.007674**
1	2	{2}	.966189		.165019	**.013797**
2	1	{3}	.302464	.165019		**.001016**
2	2	{4}	**.007674**	**.013797**	**.001016**	

Descriptive Statistics (ecpimp.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.	Standard Error
BALPRE	9	1.159778	.608000	1.630000	.350823	.116941
BALPOST	9	1.184667	.652000	1.686000	.378600	.126200
HVPRE	9	1.056889	.604000	1.362000	.303165	.101055
HVPOST	9	1.410000	.602000	1.984000	.379833	.126611

Evoked contractile property (HRT)

Summary of all Effects; design: (ecphrt.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	247.7266	8	117.3163	2.111613	.184257
2	1	121.4992	8	28.7133	4.231462	*.073697*
12	1	98.0232	8	93.0293	1.053681	.334694

Descriptive Statistics (ecphrt.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.	Standard Error
BALPRE	9	63.89222	36.56600	100.1680	19.06006	6.353353
BALPOST	9	64.26622	41.05600	96.6960	19.03179	6.343931
HVPRE	9	65.83844	37.52400	106.7920	20.05740	6.685801
HVPOST	9	72.81289	49.48600	102.2840	17.88640	5.962135

Evoked contractile property (RT + HRT)

Summary of all Effects; design: (ecpct.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	457.3182	8	249.5689	1.832433	.212841
2	1	57.5727	8	38.7218	1.486828	.257438
12	1	217.5723	8	101.1278	2.151459	.180611

Descriptive Statistics (ecpct.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.	Standard Error
BALLPRE	9	124.7138	83.9340	158.9300	22.22965	7.409884
BALLPOST	9	122.3262	101.4240	157.1140	20.82236	6.940788
HVPRE	9	126.9253	93.6360	175.4220	23.41279	7.804263
HVPOST	9	134.3713	108.1140	163.7680	17.86403	5.954678

Peak Twitch Torque/MVC Peak torque (TWT/MVC)

Summary of all Effects; design: (twtmvc.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.000805	8	.002386	.337600	.577216
2	1	.000327	8	.000861	.379479	.555000
12	1	.000505	8	.000234	2.157397	.180076

Descriptive Statistics (twtmvc.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	.173285	.110025	.289727	.059408
BALPOST	9	.171820	.107528	.272314	.049946
HVPRE	9	.156335	.093264	.220153	.046325
HVPOST	9	.169850	.086731	.218095	.043360

TRAINING TYPE I

Summary of all Effects; design: (fibt1.sta)
1-GROUP, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	45.10553	8	26.64751	1.692673	.229468
2	1	60.46593	8	82.55434	.732438	.416989
12	1	11.33810	8	28.08869	.403654	.542950

Descriptive Statistics (fibt1.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALLPRE	9	28.57769	14.68354	39.71014	9.54183
BALLPOST	9	32.29209	16.38796	46.22586	9.26051
HVPRE	9	27.46140	14.68354	41.91063	9.39543
HVPOST	9	28.93100	13.38481	50.52448	12.19745

TRAINING TYPE IIA

Summary of all Effects; design: (fibt2a.sta)
1-GROUP, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	519.5469	8	39.95580	13.00304	**.006922**
2	1	214.9694	8	90.67982	2.37064	.162200
12	1	370.0779	8	47.96051	7.71630	**.024005**

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

			{1} 28.75769	{2} 27.23250	{3} 29.94308	{4} 41.24283
1	1	{1}		.964286	.982519	**.021230**
1	2	{2}	.964286		.838941	**.011449**
2	1	{3}	.982519	.838941		**.034908**
2	2	{4}	**.021230**	**.011449**	**.034908**	

Descriptive Statistics (fibt2a.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALLPRE	9	28.75769	17.84232	38.49658	7.00974
BALLPOST	9	27.23250	14.74654	37.29904	8.23225
HVPRE	9	29.94308	17.84232	52.04741	10.97574
HVPOST	9	41.24283	23.91304	58.55856	9.33391

TRAINING TYPE IIAB

Summary of all Effects; design: (fibt2ab.sta)
1-GROUP, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	88.5617	8	22.52591	3.931548	*.082688*
2	1	102.6161	8	33.66895	3.047797	.118992
12	1	58.3180	8	28.92015	2.016517	.193370

Descriptive Statistics (fibt2ab.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALLPRE	9	12.00405	5.027174	20.88608	5.140718
BALLPOST	9	12.83516	4.200542	19.07548	4.458974
HVPRE	9	12.59542	5.993691	20.88608	5.548841
HVPOST	9	18.51761	4.408818	25.34759	7.829281

TRAINING TYPE IIB

Summary of all Effects; design: (fibt2bz.sta)
1-GROUP, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	649.650	8	60.99933	10.65011	**.011468**
2	1	1060.660	8	63.94138	16.58801	**.003569**
12	1	552.571	8	68.99703	8.00861	**.022152**

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

			{1} 30.66057	{2} 27.64025	{3} 30.00010	{4} 11.30857
1	1	{1}		.865279	.998210	**.005090**
1	2	{2}	.865279		.928457	**.013388**
2	1	{3}	.998210	.928457		**.006243**
2	2	{4}	**.005090**	**.013388**	**.006243**	

Descriptive Statistics (fibt2b.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALLPRE	9	30.66057	18.30283	40.66390	7.175507
BALLPOST	9	27.64025	13.04857	44.48161	9.661248
HVPRE	9	30.00010	7.00431	40.66390	9.753755
HVPOST	9	11.30857	1.07198	28.65731	8.844534

TRAINING FIBRE AREA TYPE I

Summary of all Effects; design: (fbareai.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	5665987	8	227263.8	24.93132	**.001062**
2	1	2328676	8	898404.1	2.59201	.146070
12	1	4544003	8	230459.7	19.71713	**.002167**

Tukey HSD test; variable Var.1 (fbareai.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} 4273.333	{2} 4071.444	{3} 4356.222	{4} 5575.444
1	1	{1}		.809357	.982077	**.002063**
1	2	{2}	.809357		.611027	**.000901**
2	1	{3}	.982077	.611027		**.003052**
2	2	{4}	**.002063**	**.000901**	**.003052**	

Descriptive Statistics (fbareai.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	4273.333	3457.000	5349.000	599.129
BALPOST	9	4071.444	3423.000	4863.000	410.186
HVPRE	9	4356.222	3632.000	5349.000	584.052
HVPOST	9	5575.444	4196.000	7645.000	1139.760

TRAINING FIBRE AREA TYPE IIa

Summary of all Effects; design: (fbareiia.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	10531107	8	261241	40.31184	.000221
2	1	16871556	8	1802095.	9.36219	.015588
12	1	7900784	8	297451.	26.56161	.000870

Tukey HSD test; variable Var.1 (fbareiia.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} 5226.222	{2} 5658.444	{3} 5371.000	{4} 7677.111
1	1	{1}		.391703	.940335	**.000261**
1	2	{2}	.391703		.689535	**.000415**
2	1	{3}	.940335	.689535		**.000285**
2	2	{4}	**.000261**	**.000415**	**.000285**	

Descriptive Statistics (fbareiia.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	5226.222	4395.000	6906.000	769.062
BALPOST	9	5658.444	4804.000	6729.000	737.910
HVPRE	9	5371.000	4395.000	6906.000	712.718
HVPOST	9	7677.111	5867.000	9744.000	1429.504

TRAINING FIBRE AREA TYPE IIb

Summary of all Effects; design: (fbareiib.sta)
1-ARM, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	9419784	8	385527.	24.43355	**.001131**
2	1	12220851	8	1251756.	9.76296	**.014131**
12	1	9189992	8	271313.	33.87234	**.000396**

Tukey HSD test; variable Var.1 (fbareiib.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} 5248.111	{2} 5402.889	{3} 5260.667	{4} 7436.444
1	1	{1}		.919454	.999951	**.000289**
1	2	{2}	.919454		.935642	**.000351**
2	1	{3}	.999951	.935642		**.000292**
2	2	{4}	**.000289**	**.000351**	**.000292**	

Descriptive Statistics (fbareiib.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	5248.111	3919.000	6767.00	894.131
BALPOST	9	5402.889	3939.000	6470.00	903.510
HVPRE	9	5260.667	4204.000	6767.00	874.478
HVPOST	9	7436.444	5643.000	10138.00	1598.341

DPX REGIONAL ARM MASS

Summary of all Effects; design: (dpxrearm.sta)
1-ARM, 2-TIME

	df	MS	df	MS		
	Effect	Effect	Error	Error	F	p-level
1	1	26759.51	8	3328.50	8.03952	**.021967**
2	1	37979.51	8	10379.12	3.65922	*.092117*
12	1	26901.47	8	1202.73	22.36703	**.001484**

Tukey HSD test; variable Var.1 (dpxrearm.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1}	{2}	{3}	{4}
			1030.478	1040.767	1030.333	1149.967
1	1	{1}		.919789	1.000000	**.000561**
1	2	{2}	.919789		.916804	**.000877**
2	1	{3}	1.000000	.916804		**.000558**
2	2	{4}	**.000561**	**.000877**	**.000558**	

Descriptive Statistics (dpxrearm.sta)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
BALPRE	9	1030.478	810.4000	1480.400	213.6895
BALPOST	9	1040.767	808.4000	1628.500	239.0704
HVPRE	9	1030.333	799.2000	1483.100	211.9409
HVPOST	9	1149.967	832.4000	1886.700	301.1454

TRAINING CONTROL VS. TRAINING SUBJECTS

DPX WHOLE BODY MASS

Summary of all Effects; design: (cntrmass.sta)
1-GROUP, 2-TIME

	df	MS	df	MS		
	Effect	Effect	Error	Error	F	p-level
1	1	41.38784	15	153.4748	.269672	.611129
2	1	2.41971	15	4.6428	.521176	.481444
12	1	.49596	15	4.6428	.106823	.748307

DPX % BODY FAT

Summary of all Effects; design: (cntrfat.sta)
1-GROUP, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	67.26865	15	23.70480	2.837765	.112759
2	1	.04085	15	1.07763	.037907	.848243
12	1	5.68791	15	1.07763	5.278166	**.036405**

Tukey HSD test; variable Var.1 (cntrfat.sta)
Probabilities for Post Hoc Tests
INTERACTION: 1 x 2

			{1} 14.88750	{2} 15.63750	{3} 12.88889	{4} 12.00000
1	1	{1}		.492628	**.006244**	**.000386**
1	2	{2}	.492628		**.000515**	**.000195**
2	1	{3}	**.006244**	**.000515**		.304198
2	2	{4}	**.000386**	**.000195**	.304198	

DPX WHOLE BODY LEAN MASS

Summary of all Effects; design: (cntrlnma.sta)
1-GROUP, 2-TIME

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.433069	15	75.46768	.005738	.940617
2	1	2.215216	15	1.52987	1.447975	.247502
12	1	5.508111	15	1.52987	3.600374	.077186

FIBER TYPE

TYPE I CONTROL VS BALLISTIC

Summary of all Effects; design: (fibicnbl.sta)
1-BALPRE

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	245.9024	13	67.71810	3.631265	*.079058*

TYPE I CONTROL VS HEAVY RESISTANCE

Summary of all Effects; design: (fibicnhv.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	316.8142	13	66.01202	4.799342	**.047295**

TYPE IIA CONTROL VS BALLISTIC

Summary of all Effects; design: (fbiiacbl.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	23.13264	13	54.71710	.422768	.526883

TYPE IIA CONTROL VS HEAVY RESISTANCE

Summary of all Effects; design: (fbiiachv.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	6.556300	13	98.61277	.066485	.800561

TYPE IIAB CONTROL VS BALLISTIC

Summary of all Effects; design: (fbiiabcb.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	1.418275	13	28.82963	.049195	.827916

TYPE IIAB CONTROL VS HEAVY RESISTANCE

Summary of all Effects; design: (fbiiabch.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.004744	13	31.51434	.000151	.990398

TYPE IIB CONTROL VS BALLISTIC

Summary of all Effects; design: (fbiibcbl.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	482.8336	13	57.71574	8.365718	**.012591**

TYPE IIB CONTROL VS HEAVY RESISTANCE

Summary of all Effects; design: (fbiibchv.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	429.3318	13	84.57596	5.076287	**.042168**

FIBER AREA

TYPE I AREA CONTROL VS BALLISTIC

Summary of all Effects; design: (fibicnbl.sta)
1-Group

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	553190.4	13	267445.3	2.068424	.1740131

TYPE I AREA CONTROL VS HEAVY RESISTANCE

Summary of all Effects; design: (icnhrar.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	811870.1	13	256467.6	3.165585	.0985821

TYPE IIA AREA CONTROL VS BALLISTIC

Summary of all Effects; design: (iiacnlar.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	522884.4	13	449885.2	1.162262	.300595

TYPE IIA AREA CONTROL VS HEAVY RESISTANCE

Summary of all Effects; design: (iiachrar.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	201072.4	13	398507.2	.504564	.490049

TYPE IIB AREA CONTROL VS BALLISTIC

Summary of all Effects; design: (iibcblar.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	1103790.	13	564252.1	1.956200	.185322

TYPE IIB AREA CONTROL VS HEAVY RESISTANCE

Summary of all Effects; design: (iibchrar.sta)
1-GROUP

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	1054301.	13	542862.4	1.942114	.186807

APPENDIX E

Consent Form and
Dual X-Ray Absorptiometry Regional Analysis Instructions

McMASTER UNIVERSITY

DEPARTMENT OF KINESIOLOGY

RESEARCH PROJECT: NEUROMUSCULAR ADAPTATIONS TO BALLISTIC AND HEAVY RESISTANCE TRAINING

INFORMATION AND CONSENT FORM

A. RESEARCHERS

Dr. Digby Sale	Department of Kinesiology
Dr. Colin Webber	Department of Nuclear Medicine
Mr. Kevin Bauer	Department of Kinesiology

B. PURPOSE

The purpose of the research is to compare the effects of heavy resistance weight lifting and rapid ballistic actions on performance, skeletal muscle adaptations, and neural adaptations.

C. DESIGN

There will be a **training** group and a **control** group, each group consisting of ten men. The measurements to be described below will be made on all subjects in both groups before and after the 20 week training period.

D. TRAINING

By random Subjects in the training group will train the elbow extensors of both arms. assignment, one arm will perform heavy resistance training: 5 sets of 5-7 repetitions with the greatest possible weight (about 85-90% of the single maximum lift), and ballistic training: 5 sets of 6 ballistic actions with a weight equivalent to 10% of the single maximum lift. The other arm will perform ballistic training only: 10 sets of 6 ballistic actions with a weight equivalent to 10% of the single maximum lift. Each training session will last approximately one hour. There will be 3 training sessions per week for a period of 20 weeks.

E. MEASUREMENTS

The following measurements will be made in each arm before and after the training program:

1. Lean Tissue Mass. This test is done using a Hologic 1000 W DPX Densitometer which is situated in the McMaster Medical Centre (Department of Nuclear Medicine). The test procedure requires the subject to lie quietly on a special table while the measurements are being made. During the test the subject receives a small dose of radiation. The test period is approximately 30 minutes on each occasion. There is no pain or discomfort associated with the procedure.

2. Muscle Biopsy. The needle biopsy procedure involves the local injection of an anaesthetic ("freezing") into the skin of the triceps area, after which a small (4 mm) incision will be made and a small (50-100 mg) piece of muscle will be removed with a special needle. After the procedure a suture will close the skin and pressure will be applied to minimize bruising. Most people report little discomfort with the procedure. It will be performed by a skilled physician who is familiar with the technique.

   From the biopsy sample muscle fibre size and fibre type distribution will be determined.

3. Evoked Contractile Properties. Percutaneous electrical nerve stimulation will be used to evoke maximal isometric twitches of the triceps brachii. The purpose of this test is to measure muscle contractile performance uninfluenced by voluntary control.

4. Electromyography. Surface recording electrodes will be placed on the skin overlying the agonist triceps and antagonist biceps muscles, to record motor unit activity during the performance tests.

5. Performance Tests. Isometric strength, weight lifting strength, and ballistic performance will be measured.

F. RISKS

Radiation dose. The procedures for measuring lean tissue mass require that the subject be exposed to a small dose of radiation equal to 0.2 mSv. To assess the risk associated with this radiation exposure, comparison can be made with the doses received in the following situations. Each member of the public in Ontario receives a whole body dose of 2.3 mSv each year as a consequence of exposure to natural radiation and radioactivity. In addition, atomic radiation workers such as x-ray technologists are each allowed a maximum annual whole body exposure of 50 mSv. It can be seen that the radiation doses received by each subject in this study are small.

Muscle Biopsy. Complications with the procedure are rare. However, in our experience with athletes, fewer than 1 in 400-500 subjects experience a local skin infection, 1 in 30-40 have a temporary (up to four months) localized loss of sensation in the skin at the site of incision, and a few subjects have mild bruising around the incision for 4-5 days. There is also the very rare (one in a million) chance that you may be allergic to the local anaesthetic.

Contractile Properties and Electromyography. These procedures are routine and often used in neurological examinations; they pose no risk.

Testing and training injuries. There is a small risk of muscle injury during training and performance testing and training. The probability of injury will be minimized by using warm-up procedures prior to maximal exertion, and by having supervision of all training sessions.

G. TIME COMMITMENT

Each subject will be required to perform 3 one hour training sessions per week for 10 weeks (Jan.-Mar.). In addition, there will be a 2 week testing period before and after the training period. During each testing period the time commitment will be ~5 hours.

H. REMUNERATION

Each subject in the training group will receive an honorarium award of $500.00 as compensation for the time committed to the study (testing and training). The award is made following successful completion of the study, which includes attendance at all training and testing sessions. No partial payments will be made. Subjects who miss sessions without just cause will be required to withdraw from the study without compensation. Each subject in the control group will receive an honorarium award of $100.00 as compensation for the time committed to the study (testing). Upon request, each subject will be advised of his test results.

I. WITHDRAWAL

Subjects are free to withdraw from the study at any time; however, doing so disallows a subject from receiving the financial award. No partial payments will be made. Upon withdrawal, partial data collected on subjects will be destroyed at request.

J. USE OF DATA

The data collected will be used in the preparation of scientific reports that will be presented at conferences and published in scientific journals. Subjects will not be identified by name in presentations and reports. No other use of the data will be made.

K. MEDICAL COVERAGE

Although extremely rare, there is the possibility of medical problems which directly result from participation in the study. The investigators will assume responsibility for required medical treatment and its cost.

L. CONSENT TO PARTICIPATE

If, after reading the above information, you are interested in participating as a

☐ **training** group subject
☐ **control** group subject

in this research project, you should read the statement below and sign in space provided.

I have read and understand the above explanation of the purpose and procedures of the project, and the conditions under which I shall participate, and agree to participate.

Signature ____________________ Witness ____________________

Date ____________________

Regional Body Composition Analysis Instructions

The body composition regional analysis is not permanently enabled since it causes the analysis to proceed more slowly; 10 to 15% slower. This software will only work if the site has body composition software with 6.10 or 7.10 software.

For 6.10 Software

1) At the Hologic menu press <Alt-F-1> to exit to DOS

2) At the DOS prompt type

```
SET_TISSPAN=1 <enter>
```

* TISSPAN is a DOS environment variable that enables TISsue SPecial ANalysis.
If you want to check if the variable is correctly set, type

```
SET <enter>
```

one of the lines on your screen should read as follows :

```
TISSPAN=1
```

3) Type

```
MAINMENU <enter>
```

4) Select a whole body scan and analyze it as usual.

5) When the final report screen is displayed, press

<SHIFT-F9>

6) The image appears elongated, with a small box displayed in the center. A maximum of seven boxes can be created by pressing the (/) key. The shape of the box is subjective, depending upon the region expected to be evaluated. The scoliosis key (*) can be used to shape the boxes into various shapes and sizes. Once the box placements are satisfactory, press <END>

* If you want to change the regional analysis before you print, press

<SHIFT-F9> to retain the previous analysis; not F10
Once you escape out of the analysis program, the regional analysis is erased and the standard body analysis is returned.

7) At the regional analysis bone report use the PgUp and the PgDn keys to access the regional analysis body composition reports.

8) The regional body composition is NOT permanently enabled since it causes the analysis to perform slowly. After the desired scans are analyzed, reboot the system to return to the standard analysis mode.

9) If you receive a warning after pressing <SHIFT-F9> :

> ***Special Analysis Not Possible Until After***
> ***This Scan Has Been Reanalyzed***

You must reanalyze the scan first by pressing <F-10>, then at the final report screen, press <SHIFT-F9> to perform regional analysis

10) If you are unable to access the tissue reports using PgUp and PgDn keys, then you most likely typed the environment variable TISSPAN incorrectly therefore repeat the installations instructions described at step two.