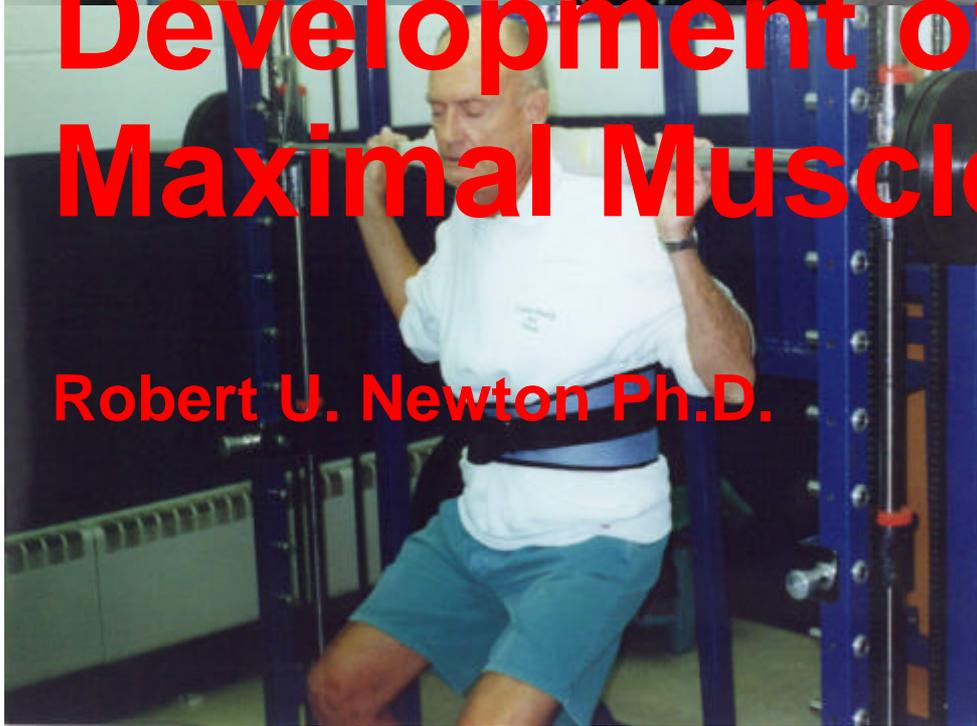


# Expression and Development of Maximal Muscle Power

Robert U. Newton Ph.D.





# **Expression and Development of Maximal Muscle Power**

A thesis submitted for the degree

## **Doctor of Philosophy**

**January, 1997**

**by**

**Robert Usher Newton**

BHMS(Hons) University of Queensland

MHMS University of Queensland

PhD Southern Cross University

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**Thank you.**

# DEDICATION

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This thesis is dedicated to the memory of

**Usher Muir Newton**

Father, friend, a great man

2<sup>nd</sup> September, 1920 - 28<sup>th</sup> November, 1996

# ABSTRACTS

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This thesis encompassed a pilot study and five separate experiments aimed at investigating the measurement, expression and development of maximal muscle power. The initial task was to assess the validity and reliability of the developed measurement system.

## Pilot Study

### ***RELIABILITY AND VALIDITY OF USING A ROTARY DIGITAL ENCODER FOR KINEMATIC MEASUREMENT DURING BALLISTIC RESISTANCE TRAINING***

The measurement of variables such as displacement, velocity, and acceleration of the load could enhance research into resistance training movements and the monitoring and design of programs. The purpose of this experiment was to assess the reliability, accuracy and precision of a digital encoder system for recording kinematic data. In the first experiment, the load was moved up and down through a fixed distance of 0.700 and 1.610 m for 20 trials. The encoder system measured each distance with an accuracy of 0.22% and 0.51% respectively and precision of measurement was 0.35% and 0.10% respectively. This was repeated for another session on the same day and then again two days later. The technical error of measurement (TEM) was calculated to be 0.9 mm and 0.8 mm for intra-day and inter-day respectively. The intra-class correlations (ICC) were 0.9999 and 0.9999 for intra-day and inter-day respectively. In the second experiment, the encoder system was compared with measurements recorded using a high-speed video system and computer digitizing. Summary kinematic variables were calculated from both sets of data including maximum and minimum displacement, velocity, acceleration and the time between maxima and minima. TEM calculated as a percentage of the measured variable (TEM%) ranged from 0.2%-5.2% and ICC from 0.115 to 0.994. It was concluded that accurate kinematic data could be obtained from the encoder system and that this data was more accurate and subsequently produced more valid velocity and acceleration data than the video measurement system. A further advantage was that the derived kinematic variables could be calculated immediately. In a third experiment, the acceleration of a free-falling mass measured by the encoder system was compared with the known value of  $g$  ( $9.81 \text{ m}\cdot\text{s}^{-2}$ ) both intra- and inter-day. A 0.56% difference between acceleration measured on days 1 and 2 was not statistically significant and the inter-day TEM was  $0.081 \text{ m}\cdot\text{s}^{-2}$  which equates to a TEM% of 0.83%. The overall conclusion was that the encoder

system was accurate and reliable for the measurement of kinematic variables of displacement, velocity and acceleration.

## **Experiment One**

### ***THE EFFECT OF A BRAKING DEVICE IN REDUCING THE GROUND IMPACT FORCES INHERENT IN MAXIMAL POWER TRAINING***

As a consequence of performing powerful exercises, such as squat jumps, impact forces placed on the musculoskeletal system during landing can lead to a potential for injury. A reduction of impact forces upon landing could therefore contribute to reduced risk of injury. Twenty subjects performed a series of loaded jumps for maximal height, with and without a brake mechanism designed to reduce impact force during landing. The braked jumps were performed on the Plyometric Power System (PPS) with its braking mechanism set at 75% of body weight during the downward phase. The non-braked condition involved jumps with no braking. Vertical ground reaction force data, sampled for 5.5 s at 550 Hz from a Kistler forceplate, were collected for each jump condition. The following parameters were then calculated: peak impact force, impact impulse and maximal concentric force. The brake served to significantly ( $p < 0.01$ ) reduce peak impact force by 61% and impact impulse by 67%. No significant differences were found for peak concentric force production. It was concluded that the braking mechanism of the PPS significantly reduced ground impact forces without impeding concentric force production. The reduction in eccentric loading, using the braking mechanism, may reduce the incidence of injury associated with landings from exercises designed to increase maximal power.

## **Experiment Two**

### ***A COMPARISON OF THE TRADITIONAL AND BALLISTIC RESISTANCE TRAINING MOVEMENTS***

The aim of this study was to compare the kinematics, kinetics and neural activation of a) the traditional bench press movement performed with the intention of maximising power output and b) the ballistic bench throw in which the barbell was projected from the hands. Seventeen male subjects completed three trials with a bar weight of 45% of the subject's previously determined 1RM. Bar displacement and velocity as well as vertical force were measured. Electromyographic (EMG) activity was recorded from the pectoralis major, anterior deltoid, triceps brachii, and biceps brachii muscle groups. Significantly higher performance ( $p < 0.001$ ) was produced during the throw movement compared with the press for average velocity ( $0.84 \pm 0.06 \text{ m}\cdot\text{s}^{-1}$ ;  $0.66 \pm 0.07 \text{ m}\cdot\text{s}^{-1}$ ), peak

velocity ( $1.31 \pm 0.1 \text{ m}\cdot\text{s}^{-1}$ ;  $0.96 \pm 0.08 \text{ m}\cdot\text{s}^{-1}$ ), average force ( $757 \pm 125 \text{ N}$ ;  $559 \pm 124 \text{ N}$ ), average power ( $595 \pm 80 \text{ W}$ ;  $350 \pm 97 \text{ W}$ ) and peak power ( $950 \pm 174 \text{ W}$ ;  $568 \pm 133 \text{ W}$ ). The average muscle activity during the concentric phase for pectoralis major, anterior deltoid, triceps brachii, and biceps brachii was higher (19%, 34%, 44%, and 27% respectively;  $p \leq 0.05$ ) for the throw condition. Further analysis of the velocity and force profiles revealed a deceleration phase during the press lasting 40% of the concentric movement which was associated with a decrease in muscle activation. It was concluded that performing traditional press movements rapidly with light loads does not create the ideal loading conditions for the neuromuscular system with regard to maximal power production. This was especially evident in the final stages of the movement in which ballistic weight loading conditions, where the resistance was accelerated throughout the movement, resulted in greater velocity of movement, force output and EMG activity.

## **Experiment Three**

### ***INFLUENCE OF LOAD AND STRETCH SHORTENING CYCLE ON THE KINEMATICS, KINETICS AND MUSCLE ACTIVATION DURING POWERFUL UPPER BODY MOVEMENTS***

Although maximal power production has been extensively studied in lower body movements, there is a paucity of research examining such movements in the upper body. This study aimed to investigate the influence of load and the stretch shortening cycle on the kinematics, kinetics, and muscle activation during maximal effort throws. Seventeen male subjects performed stretch shortening cycle (SSC) and concentric only (CO) bench throws using loads of 15%, 30%, 45%, 60%, 75%, 90% and 100% of their previously determined 1RM bench press. The displacement, velocity, acceleration, force and power output as well as EMG from pectoralis major, anterior deltoid, and triceps brachii were recorded for each throw. The results were compared using multivariate analysis of variance with repeated measures. A criterion alpha level of  $p \leq 0.05$  was used. Similar force-velocity-power relationships were determined for this multi-joint upper body movement as has been found for isolated muscles, single joint movements, and vertical jumping. The highest power output was produced at the 30% ( $563 \pm 104 \text{ W}$ ) and 45% ( $560 \pm 86 \text{ W}$ ) loads during the SSC throws. Force output increased as a function of load, however, even the lighter loads resulted in considerable force due to the high accelerations produced. Average velocity, average and peak force, and average and peak power output were significantly higher for the SSC throws compared with the CO throws. However, peak velocity and height thrown were unaffected by performing the prior counter movement possibly because the duration and range of movement allowed the muscle's ability to generate force at high shortening velocities to dominate the resulting

throw. As such, maximal power movements involving longer concentric actions than experienced during brief stretch shortening cycle movements may be limited by the muscle's force capability at fast shortening velocities.

## **Experiment Four**

### ***BALLISTIC RESISTANCE TRAINING AND THE DEVELOPMENT OF VERTICAL JUMP PERFORMANCE OF ELITE ATHLETES***

Vertical jump (VJ) performance is an essential component of volleyball. The higher the level of the athlete's ability and depth of training background the greater the challenge to produce training adaptations in VJ. Often novel methods need to be utilized. Ballistic resistance training involves performing maximal power movements by accelerating throughout the range of motion to project the load into the air i.e. a jump or throw. However, a problem arises in controlling the impact of landing and avoiding injury. This study investigated the effects of a ballistic resistance training program designed to increase the VJ performance of highly trained jumpers. A further aim was to determine if the reduction of the eccentric load during landing would inhibit improvement in VJ performance. Sixteen male volleyball players from a NCAA Division I team participated in the study. Standing vertical jump and reach (SJR) and jump and reach from a three-step approach (AJR) were measured using a Vertec. Concentric only squat jumps were also performed on a Plyometric Power System with loads of bar weight, 30%, 60%, and 90% of the subject's previously determined 1RM. Depth jumps, counter movement jumps, and concentric only squat jumps were also performed on a forceplate which measured the vertical ground reaction forces. Following the pre-testing the subjects were then randomly divided into two groups, control and treatment. ANOVA was used to ensure there was no significant difference between the groups in pre-training SJR performance. All subjects completed the usual pre-season volleyball on-court training combined with a weight resistance program which included knee flexion and extension exercises but no squats or leg press. In addition, the treatment group completed 8 weeks of squat jump training, twice each week on a Plyometric Power System using loads of 30%, 60% and 80% of their previously determined 1RM squat while the control group completed squats and leg press exercises. During each session the treatment group completed 6 sets of 6 repetitions. An electronic braking mechanism was used to reduce the load on the subject during the down phase of each jump. Both groups were re-tested at the completion of the training period. Repeated measures MANOVA was used to compare the pre and post training results for the two groups with a criterion level for significance of  $p \leq 0.05$ . The treatment group produced a significant increase in both SJR and AJR of  $5.9 \pm 3.1\%$  and  $6.3 \pm 5.1\%$  respectively. These increases were significantly greater than the pre to

post changes produced by the control group, which did not change significantly for either jump. Analysis of the data from the various other jump tests suggested increased overall force output during jumping and in particular increased rate of force development were the main contributors to the increased jump height. These results lend support to the effectiveness of ballistic resistance training for improving maximal power production in elite athletes. The specific nature of this form of training has produced improvement in VJ beyond what has been attained after prolonged traditional resistance and plyometric training. Further, the reduction of the eccentric load did not appear to inhibit the training response however this statement should be interpreted with caution as no direct comparison of braked and non-braked ballistic training was possible in the current study.

## **Experiment Five**

### ***RESISTANCE TRAINING INDUCED CHANGES IN MUSCLE POWER IN YOUNG AND OLD MEN***

Effects of 10 weeks of a periodised resistance training programme on isometric squat strength, 1RM squat strength, time course of force development (mRFD), and muscle activation (iEMG) as well as force and power output during squat jumps performed with loads of 17kg, 30% and 60% of the subject's 1RM, and muscle fiber proportion and area, were compared in young (YM, 30±5 yr) and older men (OM, 61±4 yr). An alpha level of  $p \leq 0.05$  was used as the criterion for all statistical comparisons. Of all the performance and EMG measures only 1RM squat strength changed over the 3-week control period prior to the commencement of training. Isometric squat strength was higher in the YM compared with OM at all testing occasions and increased over the training period by 23±15% and 40±42% for the YM and OM respectively however, there was no difference in percentage change between the groups. There were no significant changes in mRFD over the training period and although iEMG was significantly higher for the YM compared with OM both pre and post training, there were no significant changes with training. 1RM squat strength was significantly higher for the YM compared with the OM at all test occasions and the YM produced a significant increase with training. For the squat jumps, YM produced higher force and power at all test occasions and at all loads tested compared with the OM. The YM increased peak power output by 15±14%, 33±16%, and 26±12% and the OM by 7±5%, 36±23%, and 25±16% for the 17kg, 30% and 60% 1RM loads respectively. There were some Type II subtype differences between YM and OM pre training but these were reduced with training. Both Type I and IIa fiber areas increased in the YM and OM with training. Maximal power and force output were negatively correlated with Type I fiber proportion and positively correlated with Type IIb proportion. The results of this study suggest that 60 year old men have lower strength and power capacities than

young men and this may be related to differences in muscle fiber distribution and size. However, young and old men exhibit considerable and comparable increases in strength and power as a result of the training programme imposed.

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# LIST OF ABBREVIATIONS AND NOMENCLATURE

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AJR	three step approach jump and reach
BW	body weight
CMJ	counter movement jump
CO	concentric only
DJ	depth jump
EM	electromyography
ES	effect size
ICC	intra-class correlation coefficient
iEM	integrated electromyography
m	metres, units of displacement
$m_A$	mean of population A
$m_B$	mean of population B
mRF	maximal rate of force development
$m.s^{-1}$	metres per second, units of velocity
$m.s^{-2}$	metres per second per second, units of acceleration
MV	maximal voluntary contraction
N	Newtons, units of force
PPS	Plyometric Power System
RFD	rate of force development
mRF	maximal rate of force development
RM	repetition maximum
s	seconds, units of time
SD	standard deviation of the group standard deviation of the population
SJ	squat jump
SJR	standing jump and reach
SSC	stretch shortening cycle
TE	Technical error of measurement
TE	Technical error of measurement as a percentage of
VG	vertical ground reaction force
W	Watts, units of power



# ***Chapter 1***

## **INTRODUCTION**

---

Maximal power production in the human is achieved in the movements of sport, work, and daily living, which require the neuromuscular system to produce the highest mechanical power output of which it is capable. By definition a large amount of work is done in a short period of time, and the muscles are contracting rapidly while maintaining maximum tension. Such movements result in perhaps the most spectacular scenes in sport; the dunk shot in basketball, the rapid acceleration from the blocks in a 100m sprint, the home run hit in baseball, the world record snatch in weightlifting. On occasion, all humans are required to perform maximal power muscle actions as a part of daily life, however, this is beginning to decline with the conveniences of modern society. A most notable exception is the rapid powerful movement required when trying to recover from a slip or trip and prevent us from falling. Therefore, from both a sports performance and lifestyle perspective the expression and development of maximal power is worthy of scientific investigation.

Although there has been a great deal of research examining aerobic power (Hickson, 1977; Pollock, 1973), anaerobic performance (Gollnick & Hermansen, 1973), and muscle strength (Atha, 1981) in the human, there is a relative deficiency in knowledge concerning the expression of maximal power as well as the training and adaptation of the neuromuscular system for the enhancement of this aspect of human performance.

As early as 1935, Fenn and Marsh (1935) made the first comparisons of muscle force output at different speeds of shortening and found that force output decreased with increasing velocity resulting in what is now known as the force-velocity curve (Edgerton et al., 1986). Power is the mathematical product of force and velocity and since the work of Fenn and Marsh (1935) the relationship between force, velocity and power output has been studied in bundles of muscle fibers (Faulkner et al., 1986; Hill 1938), single joint movements (Kaneko et al., 1983; Moritani et al.,

1987; Perrine and Edgerton, 1978), and multi-joint movements such as vertical jump (Bosco and Komi, 1979; Komi and Bosco, 1978). The majority of prior research concurs that the force capability of muscle in concentric actions decreases with increasing velocity of shortening and maximal concentric power output is produced at approximately 30% of maximum isometric force and approximately 30% of maximum shortening velocity (Edgerton et al., 1986; Faulkner et al., 1986; Hill, 1938; Kaneko et al., 1983; Moritani et al., 1987).

The assessment and development of maximum strength as determined by the amount of weight which can be lifted in a single maximum effort, or one repetition maximum (1RM), has received a great deal of research attention (Atha, 1981; Berger, 1962; Häkkinen, 1989; Schmidtbleicher, 1988). 1RM strength however, is a requirement of a limited number of athletic endeavours (e.g., Power Lifting) with most sports requiring strength at faster velocities of movement, that is, an emphasis on maximal power rather than maximum force production. However, in terms of training, several studies have shown improved performance in power activities (e.g. vertical jump) following a strength training program (Adams et al., 1992; Bauer et al., 1990; Clutch et al., 1983; Wilson et al., 1993; Wilson, Murphy and Walshe, 1997). For example, research by Häkkinen and Komi (1985a) showed a 7% improvement in vertical jump following 24 weeks of intense weight training.

In a related study (Häkkinen and Komi, 1985b), a group of subjects performed movements with high power output using relatively light loads and produced significant improvement (mean 21% increase) in vertical jump. The results indicated that there might be specific training adaptations to heavy resistance versus power-type training. Heavy resistance strength training using high resistance and slow velocities of concentric muscle action leads primarily to improvements in maximal strength (i.e., the high force/low velocity portion of the force-velocity curve (*see* Figure 2.2)) and the improvements are reduced at the higher velocities. In power training, which utilizes lighter loads and higher velocities of muscle action, there are resulting increases in force output at the higher velocities as well as the rate of force development (Häkkinen and Komi, 1985b).

Although velocity specific training adaptations are observed, performance changes with training are not always consistent with this principle. The conflict results from the complex nature of maximal power production and the integration of slow and fast force production requirements within the context of a complete movement. Another confounding influence in observing clear, specific training adaptations is the fact that in untrained people, a wide variety of training interventions will produce increases in strength and power (Wilson, Murphy and Walshe, 1997). Komi and Häkkinen (1988) suggest that depending on the training status of the individual, the

response may not always follow the velocity specific training principle. For individuals with low levels of strength, improvements throughout the force velocity spectrum may be produced regardless of the training load or style used (Komi and Häkkinen, 1988). It appears that training adaptations of single factors (i.e., high force, high power) occur only after a base level of strength and power training has been undertaken. This is supported by the fact that if the athlete already has an adequate level of strength, then the increases in maximal power output in response to traditional strength training will be poor, and more specific training interventions are required to further improve the power function (Häkkinen, 1989). Thus, improvement of maximal power output in trained athletes may require more complex training strategies than previously thought (Wilson et al., 1993).

An early study by Berger (1962) found that performance of jump squats with a load of 30% of maximum resulted in greater increases in vertical jump as compared with traditional weight training, plyometric training or isometric training. Later research by Wilson et al. (1993) compared the effects of 10 weeks of training using traditional back squats, loaded jump squats, or plyometrics in the form of drop jumps, on vertical jump performance. The loaded jump squats were completed using a load which allowed the subjects to produce the greatest mechanical power output. This has been determined in this and other studies (Kaneko et al., 1983; Moritani et al., 1987) to be around 30% of 1 RM. All the training groups produced increases in squat jump (SJ) and counter movement jump (CMJ) performance except for the plyometric group which only increased CMJ height. The maximal power group produced the greatest increase in counter movement jump (CMJ) of 18% which was significantly greater than the plyometric group (10%) and weight training group (5%). For the SJ the maximal power group increased 15% which was significantly greater than the plyometric training group (7.2%) and weight training group (6.8%).

The traditional weight training increased vertical jump ability but not to the same extent as the maximal power group. This may be due to an inherent problem with traditional weight training when attempting to increase power output rather than strength. It has been observed that the load is decelerating for a considerable proportion (24%) of the concentric movement (Elliott et al., 1989) during traditional heavy weight training exercise. This percentage increases to 52% when performing the lift with a lower percentage (81%) of 1RM lifted (Elliott, et al., 1989) or when attempting to move the bar rapidly in an effort to train more specifically to the movement speed of the target activity. Plyometric and weighted jump squat training avoids this problem by allowing the athlete to accelerate all the way through the movement.

Hatfield (1989) describes a method of resistance training, termed “compensatory acceleration” in which the athlete attempts to accelerate the weight as rapidly as possible throughout

the movement but stopping the load by the end of the range of motion. Hatfield (1989) argued that this placed greater overload on the neuromuscular system thus increasing the training adaptation and also that this style of lifting was more conducive to increases in maximal power output. This thesis extends on this concept by requiring the athlete to continue to exert maximum force on the load until the point of release or takeoff from the ground. This form of training will be described throughout this thesis as “*ballistic*” resistance training. In comparing heavy weight training with lighter weight, maximal power training most studies have found the latter to be more effective for increasing maximal power production in activities such as vertical jump (Häkkinen and Komi, 1985a; 1985b; Häkkinen, 1989; Komi et al., 1982; Wilson et al., 1993).

Although research has demonstrated the efficacy of ballistic resistance training (Wilson et al., 1993; Lyttle et al., 1996) the subjects used in these studies were not at the elite level. It remains to be determined if highly trained jump athletes will respond to a ballistic resistance training program. Further, should significant changes in functional jump performance result, what characteristics of muscle function i.e. maximal strength, stretch shortening cycle capability, rate of force development, and power output have exhibited adaptations which produce this performance improvement.

With aging, muscle atrophy results from a gradual process of fiber denervation with loss of some fibers and atrophy of others (Aniansson et al., 1983; Faulkner and Brooks, 1995; Larsson et al., 1978; Lexell et al., 1988). Fast fibers show more denervation and atrophy than slow fibers (Faulkner and Brooks, 1995) and this atrophy, particularly of the fast twitch fibers, is most likely due to a combination of the aging process and physical activity levels which have declined to a chronically low intensity (Evans and Campbell, 1993; Lexell and Downham, 1992). The age-related muscle atrophy is associated with considerable decreases in muscle strength and power especially at the onset of the sixth decade both in men and women (Frontera et al., 1991; Häkkinen and Häkkinen 1991; Häkkinen et al., 1995, 1996). It has also been reported that age-related decreases in maximal power production take place actually to a greater degree than that of maximal muscle strength (Bosco and Komi 1980; Häkkinen and Häkkinen, 1991; Häkkinen et al., 1995,1996). For example, Metter et al., (1997) report that muscle power declines at a 10% faster rate than strength in aging men. Further, Skelton et al. (1994) have shown that isometric strength declines 1-2% per annum but muscle power approximately 3.5% per annum in men over 65 years old. Faulkner et al. (1986) have demonstrated that the force per cross sectional area of Type I and Type II muscle fibers is similar however the peak power output of Type II fibers is fourfold that of Type I fibers. Interestingly, more recent work (Harridge et al., 1996; Harridge et al., 1998; Larsson, et al., 1996) has revealed for the first time, that the specific tension of muscle fibers varies across

fiber type and as a function of altered levels of physical activity. Regardless, it could be expected that a selective reduction in the percentage and area of Type II fibers will result in a considerable loss of power output with aging. A loss of muscle power has been shown to have profound effects on functional activities such as speed of walking up stairs, standing up from a chair and gait speed (Bassey et al., 1992). The majority of resistance training studies with aged subjects have used traditional heavy resistance programmes (Aniansson and Gustavsson, 1981; Campbell et al., 1995; Fiatarone et al., 1990; Frontera et al., 1988). However, ballistic resistance training may be more effective in reducing muscle atrophy particularly of the Type II fibers. Further research is required into the neural and histochemical differences between young and old people as well as the training adaptations leading to increased maximal power output.

This thesis examines the development of a device specifically designed to test and train maximal muscle power. Subsequently, a series of experiments were conducted to investigate the expression and development of maximal muscle power in the human.

## **Significance of the Thesis**

This thesis is significant because it represents an in-depth examination of an important aspect of neuromuscular performance. By providing a greater understanding of how the body produces movements at the upper limit of power production capability we can provide better feedback to coaches and athletes on how to improve performance. Further, by devising testing methodologies which are more specific to the target performance being assessed, the validity of the results and the information provided is more useful for determining an athlete's strengths and weaknesses as well as assessing training outcomes. The application of training interventions based on knowledge of the mechanisms by which the body adapts to produce more powerful movements allows for the design and implementation of safer and more effective training programmes.

In terms of the general population, powerful movements are required in activities such as stair climbing, rising from a chair, and recovering balance following a slip or trip (Bassey et al., 1992). In the aged there is a selective disuse atrophy of the fast twitch fibers (Evans and Campbell, 1993; Lexell and Downham, 1992) which is most likely a result of physical activity levels which have declined to a chronically low intensity. This age-related muscle atrophy is associated with great decreases in muscle strength and especially power (Frontera et al., 1991; Häkkinen and Häkkinen, 1991; Häkkinen et al., 1995,1996). It has also been reported that age-related decreases in maximal power take place actually to a greater degree than that of maximal muscle strength (Bosco and Komi 1980; Häkkinen and Häkkinen, 1991; Häkkinen et al., 1995,1996; Newton et al., 1995). Therefore, this thesis has significance in the area of exercise and aging, both in the application of

the measurement techniques for evaluation of maximal power, and also the use of ballistic resistance training for maintaining or even enhancing maximal power output in older humans.

## Summary

Maximal muscle power production is the dominant factor in movements which aim to produce maximal velocity at the point of release, takeoff, or impact. Therefore, the ability to perform a large amount of mechanical work in a short period of time, or the ability to produce high force output at fast movement velocities, is critical to throwing, jumping, and striking activities. The qualities of neuromuscular function which contribute to maximal muscle power include: 1) maximal rate of force development (Häkkinen & Komi, 1985a); 2) muscle strength at slow and fast contraction velocities (Kaneko et al., 1983); 3) SSC performance (Bosco & Komi, 1979); and 4) coordination of movement pattern and skill (Schmidtbleicher, 1992; Young, 1993). Despite recent interest in the field there exists a paucity of research pertaining to expression and development of maximal muscle power. The methods for measuring maximal muscle power production are limited and lack applicability to the sport and work activities they are aiming to assess. Further, the effectiveness of traditional resistance training methods for developing maximal power production and athletic performance has been questioned (Häkkinen, 1989) because this type of training tends to only increase maximal strength at slow movement velocity but none of the other components contributing to maximal power production.

With the aim of investigating maximal muscle power, an electro-mechanical system interfaced to a computer was developed specifically to measure and train maximal power production in the human. A rotary digital encoder system was used to measure the kinematics of the subject's performance and thus required validation and reliability testing. High risk of musculoskeletal injury has been reported as a problem when training for maximal power (Dufek & Bates, 1990) and subsequently an electronic braking system was installed to reduce the impact forces experienced during landing. Determination of the effects of eccentric braking on the landing forces and subsequent concentric performance was required. Once the functioning of the system had been assessed a further series of three experiments were completed to investigate the expression and development of maximal power production. The first compared the kinetics, kinematics and muscle activation during ballistic (bench throw) versus traditional (bench press) resistance training movements in an attempt to explain the apparent ineffectiveness of traditional resistance training for improving maximal power production. The next experiment examined the effects of load and the SSC on force, velocity, power output and muscle activation when performing ballistic movements in the form of bench throws using loads spanning the concentric strength range. The next

experiment tested the efficacy of using ballistic resistance training with already highly trained, elite jump athletes and was designed to determine the specific adaptations in neuromuscular function which contribute to increased performance. The final experiment compared strength and maximal power output of young and older men and the neural and histochemical factors that differentiated between these two age groups. Further, the effects of a resistance training programme designed to increase muscle size, strength and maximal power output was assessed in terms of adaptation by young versus older men and to determine if such resistance training would be effective in reversing the age related loss of maximal muscle power.

This research will provide a greater scientific understanding of the biomechanics of maximal muscle power and as such have practical application to movement scientists, coaches and athletes.

# ***Chapter 2***

## **REVIEW OF RELATED LITERATURE**

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This review begins by defining maximum muscle power and then discussing why this aspect of neuromuscular function is important to human performance. To provide a theoretical framework and background information for later discussion of the research into resistance training and the development of maximal power, the histochemical and neural factors which underlie maximal power output of the neuromuscular system are explored. Subsequently, the research into maximal power production is then summarised. The factors reviewed include maximal strength, the force/velocity/power relationship, maximal rate of force development, SSC performance, and movement pattern coordination. Several controversies concerning training for improving maximal power are then discussed. First is the issue of velocity specificity of training and whether heavy or light loads should be used. Second, the use of single joint exercises and non-specific exercises and their effectiveness is debated. Third, there has been a considerable shift towards the use of the Olympic lifts and modifications of these lifts for the development of maximal power. The efficacy of this form of training is discussed in light of the available literature. It has been suggested that there is a high risk of injury when training for maximal power and as such mechanisms and possible preventative strategies are reviewed. Next the available research into maximal power production in the upper body is discussed as previous research has focussed predominantly on lower body movements. This is followed by an examination of the effects of aging on maximum muscle power and the ramifications of the changes that occur and possible preventative strategies. Mechanisms for this age related loss of muscle size, strength and power are discussed and the effects of resistance training on old people. Finally the implications of the literature review to this thesis are presented and a rationale for the present series of experiments is developed.

A vast amount of literature has been published pertinent to resistance training and subsequent neuromuscular adaptations. The scope of this review has been restricted to material relevant to the research problems presented.

## **Maximal Power Production Defined**

Power can be defined as the force applied multiplied by the velocity of movement (Knuttgén and Kraemer, 1987). As the work done is equal to the force times the distance moved (Garhammer, 1993) and velocity is the distance moved divided by the time taken, power can also be expressed as work done per unit time (i.e., the rate of doing work) (Garhammer, 1993).

$$\text{work} = \text{force} \times \text{distance}$$

$$\text{velocity} = \frac{\text{distance}}{\text{time}}$$

$$\text{power} = \text{force} \times \text{velocity}$$

therefore:

$$\text{power} = \text{force} \times \frac{\text{distance}}{\text{time}} = \frac{\text{work}}{\text{time}}$$

Power output for the athlete can range from 50-60 W produced during light cycling or jogging to around 7000 W produced during the second phase of the pull for the Olympic clean (Garhammer, 1993). The purpose of this review will be to examine the highest level of power output, that which can be produced in one or two muscular contractions. Gollnick and Bayly (1986) have termed this “maximal instantaneous power” however for the purposes of this review and the thesis as a whole, the term “maximal power” will be used.

## **Why is Maximal Power Important?**

Maximal power output is the main determinant of performance in activities requiring one movement sequence with the goal of producing a high velocity at release or impact (Young, 1993). Neuromuscular actions, which maximise power production, are required in throwing, jumping, and striking activities. In addition, sudden bursts of power are required when rapidly changing direction or accelerating during various sports or athletic events (e.g., football, basketball, soccer, baseball, and gymnastics).

As an example, the height to which an athlete jumps when rebounding in basketball is determined purely by the velocity with which he or she leaves the ground. At the bottom of the movement the body stops momentarily (Figure 2.1) and as the athlete extends the trunk, hips, knees, and ankles, the body is accelerated upward to a maximum takeoff velocity as the athlete leaves the ground. This takeoff velocity is determined by the force that the muscles can generate against the ground multiplied by the time that the forces are applied, termed impulse, minus the impulse due to

the body-weight. In other words, takeoff velocity in the vertical jump is determined by the difference between the body-weight impulse and the impulse created by the actions of the body segments (Winter, 1990).

Once the athlete has left the ground they can no longer apply the force and the faster the acceleration the shorter the time between the bottom of the movement and takeoff (e.g. Figure 2.1 - 268 ms). It is here that we encounter the crucial importance of maximum muscular power. As an athlete attempts to maximize his or her power output, the time over which he or she can apply force and accelerate the body decreases. Therefore, three mechanical properties of muscle are paramount:

the ability to develop a large amount of force in a short period of time. This has been termed the maximum rate of force development (mRFD);

the ability of the muscle to produce a high force at the end of the eccentric phase and the early concentric phase;

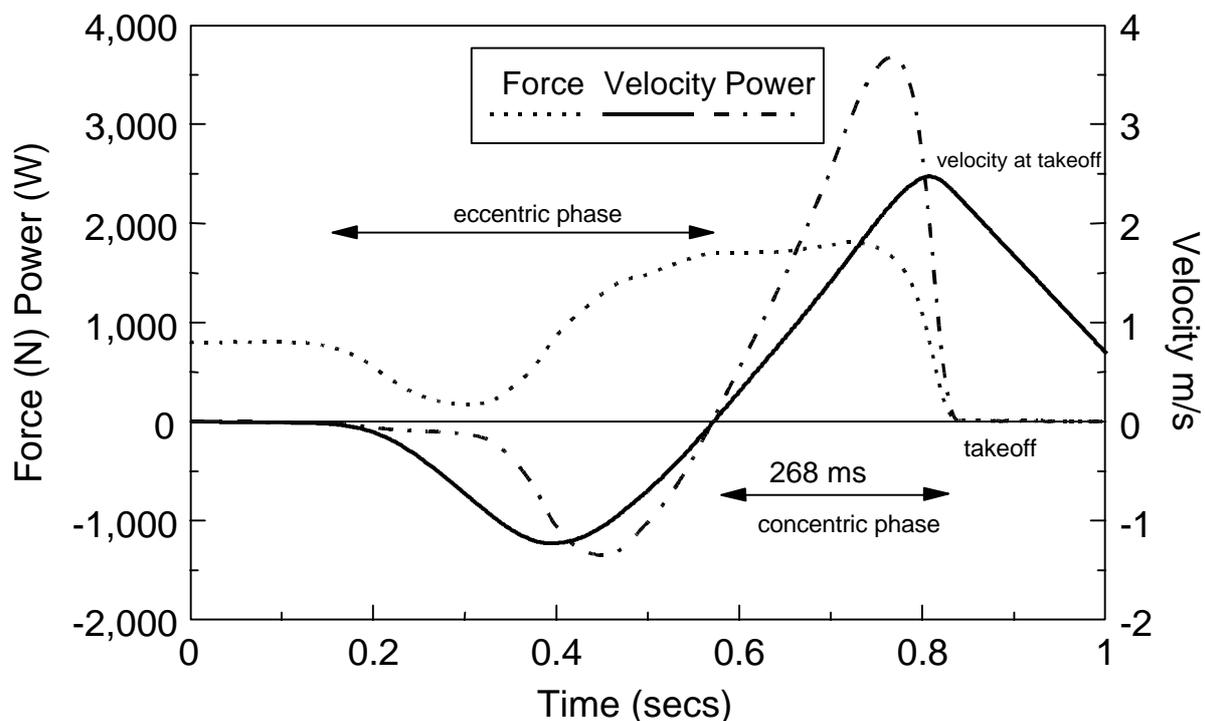
the ability of the muscle to continue to produce high force output as its velocity of shortening increases.

There are a number of factors that contribute to maximizing these three properties. The discussion of each of these factors individually will assist our understanding of the effects of different training strategies and how they may influence training efficiency.

## **Factors Contributing To Maximal Power Output**

### ***Intra-Cellular Factors Effecting Maximal Power Output***

Maximal power is produced by a maximal rate of cross-bridge cycling at the level of actin and myosin and the total quantity of myofilaments. It is instructive then to examine the factors that may influence these two quantities:



**Figure 2.1** Vertical ground reaction force, centre of mass velocity, and power output of the subject during a vertical jump with counter movement. Note that the concentric muscle action is only 268 ms in duration. The resulting takeoff velocity is determined by the sum of the forces (impulse) which can be produced during this short time period.

### Cross-Sectional Area

As the concentration of actin and myosin per cross-sectional area of muscle is constant, thus cross-bridges per unit area of muscle is constant, maximal power output is very much dependent on muscle cross sectional area (Gollnick and Bayley, 1986). The total power that can be developed by a muscle or group of muscles is a function of the total cross-sectional area of the muscles that can be activated. Such increases have been produced through heavy resistance training by synthesis of additional contractile units (Prince, Hikida and Hagerman, 1976). However, it should be noted that the increase in strength and power output is not linearly related to the increase in cross-sectional area and this may be due to an alteration in the pennation angle of the muscle fibers (Ikai and Fukunaga, 1970) which will be discussed in detail later in this chapter.

### Muscle Hypertrophy and Power

It has been stated above that high muscle force is a component of power. This ability for high force production or strength can be increased by the muscle growing larger (hypertrophy) and/or through improved neural activation of the muscle (Schmidtbleicher and Buehrle, 1983).

One long held belief is that excessive hypertrophy training will disadvantage the power

athlete who must work against his/her body weight (e.g. jumpers, sprinters). However, increases in muscle size are usually accompanied by increases in muscle strength (Schmidtbleicher, 1992). If appropriate “power type” training is included, the power to weight ratio especially crucial in jumping events, should also be increased rather than decreased.

Increased strength does not always accompany hypertrophy (Sale, Martin and Moroz, 1992). In one study, eight men (20-30 years) weight trained 3 days per week for 19 weeks. Training sessions consisted of six sets of a leg press exercise on a weight machine, the last three sets with the heaviest weight, which could be used for 7-20 repetitions. In comparison to a control group (n=6) only the trained group increased weight lifting performance (1RM) by 29%. Left and right knee extensor cross-sectional area also increased significantly in the trained group by 11% percent. Notably however, training caused no increase in maximal voluntary isometric knee extension strength, electrically evoked knee extensor peak twitch torque, or knee extensor motor unit activation. These data indicate that a moderate but significant amount of hypertrophy induced by weight training does not necessarily increase performance in an isometric strength task different from the training task but involving the same muscle group. The failure of evoked twitch torque to increase despite hypertrophy may further indicate that moderate hypertrophy in the early stage of strength training may not necessarily cause an increase in intrinsic muscle force generating capacity (Sale, Martin and Moroz, 1992).

It has been demonstrated that increases in cross-sectional area of muscle may not result in proportional increases in force generating capacity. A study by Maughan, Watson and Weir (1984) examined muscle strength and cross-sectional area in a group of 35 healthy untrained male subjects and 8 subjects who had been engaged in a strenuous weight-training programme. The maximum voluntary knee extension force which could be produced by the untrained subjects was  $742 \pm 100$  N. The trained subjects could produce a significantly greater force ( $992 \pm 162$  N). Cross-sectional area of the knee-extensor muscle group was significantly greater in the trained than untrained group as expected. Further, a significant correlation existed between strength and muscle cross-sectional area however; there was a significant inverse relationship between muscle cross-sectional area and the ratio of strength to cross-sectional area (Maughan, Watson and Weir, 1984).

A possible explanation for the discrepancy between increases in muscle size and force output could be the changes in muscle architecture which accompany hypertrophy. A cross-sectional study by Kawakami, Abe and Fukunaga (1993) measured muscle-fiber pennation angles in vivo with the use of ultrasonography to investigate the relationship between fiber pennation and muscle size for 32 male subjects ranging from untrained to highly trained bodybuilders. Significant differences were observed between normal subjects and bodybuilders in muscle thickness and

pennation angles ( $p < 0.01$ ). In addition, there were significant correlations between muscle thickness and pennation angles for both long ( $r = 0.884$ ) and medial ( $r = 0.833$ ) heads of the triceps brachii, suggesting that muscle hypertrophy involves an increase in fiber pennation angles (Kawakami, Abe and Fukunaga, 1993)

A more recent longitudinal training study has examined changes in muscle CSA, pennation angle and force output (Kawakami et al., 1995). Five men underwent unilateral resistance training of the elbow extensor (triceps brachii) muscles for 16 weeks. Before and after training, muscle layer thickness and fascicle angles of the long head of the triceps muscle were measured in vivo using ultrasound, and fascicle lengths were estimated. Series anatomical cross-sectional areas (ACSA) of the triceps brachii muscle were measured by magnetic resonance imaging, from which muscle volume ( $V_m$ ) was determined and physiological cross-sectional area (PCSA) was calculated. Elbow extension strength (isometric, concentric and eccentric at 30, 90 and 180 degrees. $s^{-1}$ ) was measured using an isokinetic dynamometer to determine specific tension. Muscle volumes, ACSA, PCSA, muscle layer thickness and fascicle angles increased after training and their relative changes were similar, while muscle and fascicle length did not change. Muscle strength increased at all velocities; however, specific tension decreased after training. Increase in pennation angles, which are the result of increased  $V_m$  and PCSA, would seem to imply the occurrence of changes in muscle architecture such that the angle at which force is applied to the tendon is increased. The result is that the component of the muscle force directed along the tendon and thus applied to the bone is reduced and this explains the reduced force per cross-sectional area. This not to say that the hypertrophy does not normally result in increased strength. However, with increasing hypertrophy the gains in strength as a proportion of increase in muscle size are diminishing (Kawakami et al., 1995).

With regard to maximal power production the specific effects of hypertrophy are not known. As discussed earlier however, increases in muscle force production will result in increases in maximal power output. However, the effects on maximal power production of muscle hypertrophied to its maximal genetic potential is not known. Theoretically it could be detrimental to muscle speed of contraction due to the changes in muscle architecture already outlined. Although the majority of research has shown that force output increases with increasing muscle hypertrophy, it is not known if the effect on maximal power production is similar or in fact if a pennation angle may be reached at which power output decreases. These questions require further research.

Although involving only a small number of subjects, MacDougall (1986) has shown that the sarcoplasmic reiticulum/myofibrillar volume ratio in the gastrocnemius of bodybuilders ( $N = 4$ ), is

less than that of untrained subjects ( $N = 4$ ). It is not known if this dilution of sarcoplasmic reticulum in hypertrophied fibers is sufficient to affect the mechanics of calcium release and uptake. However, it may provide a partial explanation for the prolonged twitch contraction time measured in a group of bodybuilders and weightlifters (Sale et al., 1983). How this affects maximal power production of hypertrophied muscle is not known.

In practical terms, the type of high volume training (e.g., 6-14 sets of 10RM) of isolated joint movements needed for dramatic muscle hypertrophy, would negatively impact on the time available for power and skill training time and thus not be efficient in terms of improving on-field performance. Thus, here is where training specificity dramatically separates itself between power sports and body building. Nevertheless, hypertrophy training may be needed at some point in the athlete's career or training cycles to maintain a certain level of muscle size appropriate to the demands of the sport.

### **Energy Availability**

It has never been demonstrated that physical training alters the ATP required to produce contraction for a given fiber type (Gollnick and Bayley, 1986). Thus, it can be argued that the energy demand and maximal power production per contractile unit of muscle are constant. The quantity of ATP required to maximally activate cross-bridge cycling for one or two contractions is contained in the muscle and can be replenished from creatine phosphate stored in the muscle. As such, all of the energy required for maximal power production is available in the muscle and such efforts do not rely on immediate energy production by the metabolic pathways. Expansion of these pathways through training is therefore of no consequence (Gollnick and Bayley, 1986).

### **Muscle Fiber Type**

Mammalian skeletal muscles and muscle fibers assume an organisation and composition specialised to function optimally in a given set of environmental conditions (Hochachka, 1976). There is a wide variation in the expression of this specialisation between different species and even between muscles of the same species. However, it is well recognised that motor units can be separated into two fundamental categories, each highly adapted for the performance of certain contractile behavior (Saltin and Gollnick, 1983).

In general, slow twitch (ST) or Type I muscle fibers are specialised for protracted usage at relatively low velocities. Fast twitch (FT) or Type II fibers, in contrast, are specialised for bursts of work in which large power outputs and high velocities are generated for relatively brief periods of time (Green, 1986). To express these functional differences the two fiber types have consistent and

fundamental differences in their ultrastructural and metabolic properties (Pette and Heilman, 1979). The sarcoplasmic reticulum (encompassing ATPase activity, calcium release and uptake characteristics, phosphoprotein formation, and peptide pattern), the contractile proteins (isozymes of myosin and troponin), myosin ATPase activity, and the enzymes of energy metabolism (aerobic and anaerobic) all appear to undergo a coordinated expression (Green, 1986). In the case of FT fibers, calcium uptake by the sarcoplasmic reticulum, cross-bridge cycling rate, ATP hydrolysis, and anaerobic regeneration of ATP are all uniformly high (Green, 1986).

Categorisation of muscle fibers as ST or FT types is performed by qualitative histochemical analyses of the myofibrillar adenosinetriphosphatase activity. The FT fiber type can be further distinguished into subdivisions determined largely on the basis of histochemical criteria (Reichmann and Pette, 1982). The most popular fiber typing method for human use has recognised three categories of Type II fibers, IIa, IIb, and IIc (Brooke and Kaiser, 1970) with each postulated to have highly specific functionality.

Comparing the maximum contraction velocity and power output, Faulkner et al. (1986) have estimated a fourfold difference in the human between fiber types. This is the result of the cellular mechanisms underlying the functional specialisation exhibited by ST and FT fibers. Myosin ATPase ranges from two to three times higher in FT as compared with ST fibers (Thorstensson et al., 1975) which is paralleled by differences in isometric contraction time and maximal shortening velocity. For example, Garnett et al. (1978), using electrical stimulation of single motor units in humans, have reported contraction times ranging from 90 to 110 msec for ST motor units and from 40 to 84 msec for FT motor units.

In muscles characterised by high power outputs and high rates of force development, there is a necessity to provide not only high rates of ATP regeneration but also to satisfy the nearly instantaneous requirement for large amounts of ATP (Green, 1986). In the human concentrations of ATP and CP are generally comparable between fiber types however, higher rates of ATP production in FT fibers is facilitated on the basis of approximately 30% higher creatine kinase activity and 80% higher myokinase activity (Thorstensson et al., 1977).

In view of the differences between the ST and FT muscle fibers, it is not unexpected that athletes who specialise in events requiring rapid development of force and high maximal power output tend to have a predominance of FT fibers (Costill et al., 1976). There has also been evidence published demonstrating a positive relationship between percentage of FT fibers and power output (Thorstensson et al., 1976). This relationship appears to be most pronounced in maximal contractions involving high velocities (Coyle et al., 1979) or when the rate of force development is

high (Viitasalo and Komi, 1978).

For most human muscles, mATPase-based fiber types correlate with the myosin heavy chain (MHC) content. Thus, each histochemically identified fiber has a specific MHC profile. Although this categorization is useful, it must be realized that muscle fibers are highly adaptable and that innumerable fiber type transients exist (Staron, 1997). Although the major populations of fast and slow are, for the most part, established shortly after birth, subtle alterations take place throughout life. These changes appear to relate to alterations in activity and/or hormonal levels, and perhaps later in life, total fiber number (Staron, 1997). These fibers, however, are not fixed units but represent highly versatile entities capable of responding to altered functional demands and a variety of signals by changing their histochemical profiles (Pette and Staron, 1997). This adaptive responsiveness is the basis of fiber type transitions with the fiber population of a given muscle in a dynamic state, constantly adjusting to the current conditions. The full range of adaptive ability spans fast to slow characteristics. However, it is now clear that fiber type transitions do not proceed in immediate jumps from one extreme to the other, but occur in a graded and orderly sequential manner (Pette and Staron, 1997). At the molecular level, the best examples of these stepwise transitions are myofibrillar protein isoform exchanges (Staron, 1997). For the myosin heavy chain, this entails a sequence going from the fastest (MHCIIb) to the slowest (MHCI) isoform, and vice-versa. Depending on the basal protein isoform profile and hence the position within the fast-slow spectrum, the adaptive ranges of different fibers vary (Pette and Staron, 1997).

Resistance training has been shown to exert a strong influence on muscle fiber characteristics and MHC profile. Hather et al. (1991) reported that 19 weeks of heavy resistance training caused a decrease in the percentage of Type IIb and an increase in the percentage of Type IIa fibers as determined by qualitative histochemical analyses of myofibrillar adenosinetriphosphatase activity of biopsies of vastus lateralis muscle. These results suggest that resistance training had caused a transformation among the fast-twitch fiber subtypes. A paper published later by the same group (Adams et al., 1993) reported results of analysing the same tissue biochemically for myosin heavychain (MHC) composition by use of sodium dodecyl sulfate-polyacrylamide gel electrophoresis and histochemically for fiber types by use of myofibrillar adenosinetriphosphatase activity. The results showed that after training, IIb MHC composition decreased from  $19\pm 4\%$  to  $7\pm 1\%$ . In contrast, IIa MHC increased from  $48\pm 3\%$  to  $60\pm 2\%$ . These responses were essentially mirrored by alterations in fiber type distribution. The percentage of Type IIb fibers decreased from  $18\pm 3\%$  to  $1\pm 1\%$ , whereas the percentage of Type IIa fibers increased from  $46\pm 4\%$  to  $60\pm 3\%$ . Neither I MHC composition nor Type I fiber percentage changed with training. These results suggest that heavy resistance training alters MHC composition in

human skeletal muscle (Adams et al., 1993).

In another study (Staron et al. 1990) twenty-four women completed a 20-week heavy-resistance weight training program for the lower extremity. The subjects completed 2 sessions per week consisting of three sets each of full squats, leg presses, leg extensions, and leg curls. All exercises were performed to failure using 6-8 RM. Weight training caused a significant increase in maximal isotonic strength (1 RM) for each exercise. Biopsies were obtained before and after training for histological and histochemical analysis. Six fiber types (I, IC, IIC, IIA, IIAB, and IIB) were distinguished following myosin ATPase histochemistry. Areas were determined for fiber Types I, IIA, and IIAB + IIB. The heavy-resistance training resulted in significant hypertrophy of all three groups: I (15%), IIA (45%), and IIAB + IIB (57%). In addition, the training resulted in a significant decrease in the percentage of IIB with a concomitant increase in IIA fibers, again supporting the postulation that strength training may lead to fiber conversions (Staron et al., 1990).

These studies have established that muscle fibers, although bound somewhat to their main classification as ST or FT, are capable of considerable plasticity, particularly of the FT fibers. As already stated, a positive correlation exists between the percentage of fast fibers and peak force output moderate-to-high velocities. Consequently, peak power output is substantially greater in subjects possessing a predominance of fast fibers. The mechanical properties of slow and fast muscles do adapt to programs of regular exercise. Resistance training has been shown to increase the force and power output and this is in part a result of fiber hypertrophy but also a shift between fiber subtypes and other alterations favoring increased contraction speed and thus maximal power output.

### ***Neural Factors Effecting Maximal Power Output***

Human strength and power is determined not only by the size of the involved muscles but also by the ability of the nervous system to appropriately activate the muscles. To produce high power output the agonists must be fully activated, muscles assisting or coordinating the movement (synergists) must be appropriately activated, and the muscles, which produce force in the opposite direction to the agonists, termed antagonists, must be appropriately activated (Sale, 1992). Therefore, the control of movement by the nervous system is critical to strength and power production and this explains the large increases in strength which are apparent in the first few training sessions for athletes performing an exercise to which they are not accustomed (Sale 1992). Adaptive changes in the nervous system optimise control of the muscles involved in the exercise through a number of possible mechanisms.

## **Increased Activation of Agonists**

All muscles are innervated by a few to several hundred motor units. To produce maximum force, all of the motor units in the muscle must be activated. As motor units range from slow to fast in their characteristics they can be classified as low and high threshold for recruitment. According to the “size” principle, motor units are recruited in order according to size as a voluntary contraction increases from zero to maximal (Hannerz, 1974). Thus the largest and fastest motor units are only recruited during maximal or near-maximal contractions. In the early phase of training with a new exercise a human may acquire the ability to recruit the high threshold motor units, thus achieving increased activation of the agonists and increased force output (Sale, 1992). As muscle force is also controlled by the frequency of firing of the motor units a further neural adaptation may be the ability to fire all the motor units at a sufficiently high rate to produce maximum force. For example, Häkkinen et al. (1985a) have reported an increase in the quantity of electromyographic activity recorded before and after a heavy resistance training programme. This increase indicates either more motor units are being recruited during the maximal isometric actions tested, the motor units are being activated at a higher rate, the level of synchronization among the action potentials discharged by motor units is increased, or some combination of these three.

## **Neural Contribution to Rate of Force Development**

As previously mentioned, the ability of the muscle to increase force rapidly from a relaxed state may be crucial for maximal power production. Although there are aspects of the contractile machinery itself which effect the muscle’s rate of force development and contraction speed, further neural components can also have an influence. For example, Häkkinen et al. (1985b) have reported increased rate of force development as a result of what the authors termed “explosive jump training”. Accompanying the performance increase was an increase in the rate of onset of motor unit activation indicating some adaptation of the neural system towards improving rapid force increases.

It is possible that rapid ballistic muscle actions differ from slow movements in terms of organization and central command of nervous system control (Desmedt and Godaux, 1979). This may explain in part the velocity specific training adaptations which have been observed in which training with rapid movements increases strength at high contraction velocities but has little influence on isometric strength or strength measured during slow movements (Duchateau and Hainaut, 1984).

As stated earlier, increased firing rate is a mechanism by which a single motor unit can increase the force it produces. However it has been observed that during maximal voluntary

contractions the firing rate is well above that required to elicit maximum isometric force (Grimby et al., 1981; Kamen et al., 1995; Macefield et al., 1996). The high rate will however result in an increased rate of force development (Sale, 1992) with the highest motor unit firing rates being recorded during maximal ballistic actions. Desmedt and Godaux (1977) found that in slow tracking ramp contractions, the instantaneous frequency of single motor units was initially rather low (5-15Hz) and it increased as the ramp force increased. By contrast, in (strong) ballistic contractions, the same units discharged at an unusually high instantaneous frequency (60-120Hz) early in the burst and the firing frequency decreased thereafter. Such a pattern appears characteristic of ballistic contractions and is advantageous in terms of increased rate of force development during the initiation of ballistic actions. Although it has not been proven, a further neural adaptation to maximal power training may be an ability to increase the maximum firing rates in ballistic actions (Sale, 1992) and may explain the more rapid onset of EMG after jump training observed by Häkkinen et al. (1985b).

### **Pre-Movement Silence**

Agonist pre-movement silence (PMS) has been described as a brief period of relative quiescence in active skeletal muscle prior to phasic activation (Walter, 1988). The PMS most often occurs in maximal ballistic actions but is not always present. Mortimer et al. (1987) suggest that PMS may increase peak muscular force by bringing motoneurons into a non-refractory state prior to their activation. Further, the fact that it occurs on some, but not all, trials within single subjects and has a variable duration from trial to trial suggests that it may be a learned, rather than automatic, motor response (Mortimer et al., 1987). Thus, an increased occurrence of PMS may be an adaptation to high velocity training leading to enhanced force and power (Sale, 1992). The PMS may also induce a brief stretch shortening cycle increasing the rate of force development and peak force of the concentric phase of the movement (Walter, 1988).

### **Preferential Recruitment of Motor Units**

Although the recruitment of motor units generally proceeds according to the “size” principle already discussed, apparent violations of this principle may occur. In twitch contractions selective activation of FT motor units has been observed if the muscle was relaxed prior to the twitch and great effort was used to elicit the twitch and minimum duration of the twitch was intended (Grimby and Hannerz, 1977). Further, it was suggested that the order of recruitment and the relative roles of the two motor unit types are adapted to the mode of contraction. Contrary to measurements in experimental animals (Burke et al., 1973) there does not appear to be any association between the contraction speed and recruitment threshold of motor units in human muscle (Bigland-Ritchie et al.,

submitted). It has, however, been shown that the recruitment of motor units may deviate from that predicted by the Size Principle during eccentric contractions (Nardone et al., 1989). Perhaps with specific training, this preferential recruitment can be enhanced leading to increased maximal power capacity.

### **Selective Activation of Agonists Within a Muscle Group**

Preferential activation of some muscles over others in a functional group may occur depending on the velocity of movement, type of action and movement pattern (Sale, 1992). For example, fast muscles, i.e. those with a relatively high proportion of fast twitch motor units, may be preferentially activated over slow muscles when high velocity movements are attempted (Sale, 1992). The relative contribution of agonist muscles has been studied during pedalling on a bicycle (Duchateau et al., 1986). The electromyographic (EMG) activity of the different components of triceps surae, namely soleus and medial gastrocnemius, was recorded and analyzed for increasing pedalling speed performed against increasing resistance. The results indicated that soleus IEMG increases linearly with increasing load (10-70 N) at constant speed (60 rpm), whereas no change was noted in medial gastrocnemius below 40 N. In contrast, when the pedalling speed was increased (from 30 to 170 rpm) at constant load, medial gastrocnemius exhibited the largest increase (Duchateau et al., 1986). The authors suggested that the different muscles of the triceps surae make specific contributions to the development of the mechanical tension required to maintain or increase the speed of movement. Although it has not been proven, there is the potential for strength and power training to improve performance by more effective preferential recruitment of certain agonists within a group.

### **The Bilateral Deficit**

Neural activation patterns and skill are intrinsic to the powerful performance of a given movement. Many activities are unilateral in that they involve one arm or leg producing the movement while the other undergoes recovery or stabilizing movements. Sale (1992) has described the phenomenon of bilateral deficit as the difference between the force output when the left and right sides act simultaneously and the sum of the forces produced by the left and right limbs acting alone. Training may increase or reduce the deficit as demonstrated by tests on rowers who have been recorded as stronger in bilateral leg press than the sum of single leg press and cyclists who normally alternate leg actions and display a large deficit (Howard and Enoka, 1991; Secher, 1975).

In a study by Herbert and Gandevia (1996) examining the thumb adductor muscle it was determined that subjects could only activate at 90.3% of maximum when contracting this muscle

alone. However, this percentage was not altered by simultaneous contraction of the contra-lateral thumb or elbow flexors which questions the theory that the bilateral deficit is due to an inability to provide maximum activation to both sides of the body simultaneously. Such a deficit is evident in muscle actions involving large muscle groups regardless of the underlying cause and therefore, when training for specific unilateral activities (e.g. kicking) it may be advisable to train using single leg presses and knee extensions as opposed to exercising both legs simultaneously.

### **Cross-Training Effect**

Any discussion of the bilateral deficit should also address the phenomenon of the cross-training effect. It has been observed in a number of studies that the training of one limb is associated with increased voluntary strength in the contralateral untrained limb (Ikai and Fukunaga, 1970; Komi et al., 1978; Moritani and de Vries, 1979) and the effects of skill training may also be transferred in this manner (Hellebrandt, 1951). It appears that the increase in voluntary strength in the untrained limb is attributable to neural adaptation. This is supported by the observation that there is no increase in muscle size (Ikai and Fukunaga, 1970), muscle fiber size (Houston et al., 1983), or evoked contraction strength (Duchateau and Hainaut, 1984) in the untrained limb. Perhaps the most interesting example of this phenomenon is the finding of Yue and Cole (1992) that there is an increase in strength in a contralateral limb after training with imagined (not real) contractions. Although no specific research is available, it could be expected that maximal power production would also exhibit a cross-training effect.

### **Coordination of Movement Pattern and Skill**

Power performance is affected by the interaction between agonists, antagonists and synergists involved in the joint movement. To produce a fast movement velocity, resistance must be low. Although the agonist muscle may be able to apply great force in a short period of time, there must be a complementary relaxation of the antagonists. Specific training movements have been postulated to reduce the co-contraction of antagonists and increase the coordination of agonist and synergist activity (Schmidtbleicher, 1992; Young, 1993), however, the movement must be specific to the target activity in terms of pattern and speed.

Carolan and Cafarelli (1992) found that hamstring coactivation during knee extension MVC decreased significantly after 8 weeks of isometric resistance training. Extension MVC force increased significantly, but there was no change in the maximum IEMG of vastus lateralis, indicating that the degree of activation did not increase. The authors concluded that the reduction in hamstring coactivity reduced the opposing force to the contracting quadriceps resulting in a greater

net extension force. The changes in coactivation could be a learned adaptation manifested as an improvement in coordination or skill (Rutherford and Jones, 1986). This could be mediated by mechanisms in the central nervous system and this is supported in research showing decreased coactivation in both the trained and contralateral untrained sides (Carolan and Cafarelli, 1992).

It is clear that the more specific the training movement is to the target activity then the greater the transfer of improvements to the athletic performance. This method may be better described as coordination training rather than strength or power training (Schmidtbleicher, 1992). Thus, specific skill and coordination of force application are important contributors to performing movements with high power output.

Bobbert and Van Soest (1994) completed a simulation study into the effects of increased muscle strength on jump height. Interestingly, this initially resulted in a decrease in height jumped. The authors had to modify the control of the neuromuscular system, commonly referred to as coordination, timing or technique, to actually produce an increase in jump height. This experiment confirmed what coaches have long known. In order to take full benefit of an increase in muscle strength, coordination needs to be adapted. If the aim of the training programme is to increase jump height then any muscle strength training exercises need to be accompanied by exercises, which allow the athletes to practice with their changed muscles (Bobbert and Van Soest, 1994).

### ***Stretch Shortening Cycle***

Most powerful activities involve a counter movement during which the muscles involved are first stretched and then shortened to accelerate the body or limb. This action of the muscle is called a stretch shortening cycle (SSC) (Komi, 1986) and involves many complex and interacting neural and mechanical processes. A great deal of research has been directed toward the study of the stretch shortening cycle (Bobbert et al., 1996; Bosco and Komi, 1979; Bosco et al., 1983; Ettema et al., 1990; Gollhofer and Kyröläinen, 1991; Häkkinen, 1989; Komi et al., 1982; Schmidtbleicher, 1988) because it has been observed that performance is greater in SSC movements than if the activity is performed with a purely concentric action (Bosco and Komi, 1979).

In a cross-sectional study, Bosco et al. (1982) observed differences between squat jump (SJ) and counter movement jump (CMJ) heights of 18%-20%. A SJ is a purely concentric jump initiated from a crouch position. The CMJ is initiated from a standing position and the athlete performs a preparatory dip movement then jumps upwards.

### **Why is CMJ Height Greater Than SJ Height?**

This question remains a contentious issue in biomechanics but at least six possible

explanations may be offered (Bobbert et al., 1996; Walshe et al., 1997):

1. It may be that subjects are simply not used to performing SJ and as such do not have the proper coordination to perform the jump with optimal control. Therefore the jump will be less than the maximum achievable height as determined by the properties of the musculoskeletal system (Bobbert et al., 1996).

2. In the SJ the muscles are unable to achieve a high level of force prior to the start of the concentric contraction (Bobbert et al., 1996). When performing maximal voluntary contractions, it takes time before the muscle force has reached its maximum. This is due to a number of factors:

- a) there is a finite rate of increase in neural stimulation to the muscle from the central nervous system;
- b) a delay is apparent between stimulation and actin-myosin coupling;
- c) due to the interaction of the contractile elements and series elastic elements there is a further delay in the transmission of the tension to the bone.

This delay can be avoided by allowing the muscle to build up to a maximally activated state prior to the start of the concentric contraction, either by performing an isometric contraction (isometric pre-load) or during a counter movement as in a CMJ (Walshe et al., 1997).

3. There is the possibility for the storage and reutilisation of elastic energy. During the counter movement in a CMJ the active muscles are pre-stretched and absorb strain energy. This energy is temporarily stored in the series elastic elements and then reutilised during the concentric phase resulting in an increased work output for the CMJ over the SJ (Avis et al., 1986; Roberts et al., 1997).

4. The muscle stretch that occurs during the counter movement triggers spinal reflexes, which help to increase muscle stimulation during the concentric phase (Bosco et al., 1982). The increase in stimulation results in increased contraction force during the concentric phase and thus greater jump height (Gollhofer and Kyröläinen, 1991; Schmidtbleicher, Gollhofer and Frick, 1988).

5. It is possible that the pre-stretch of the active muscle alters the properties of the contractile machinery (Cook and McDonagh, 1995). This enhancement has been termed potentiation with the effect being greater with increased speed of stretch and decreasing with time elapsed after the pre-stretch.

6. There is a considerable interaction between the contractile mechanics and the tendinous recoil of the musculo-tendinous unit (Ettema et al., 1992). Due to the elastic nature of tendon, the additional

force present at the start of the concentric phase following the stretch or eccentric phase results in relatively greater tendinous extension with less myofibrillar displacement. Therefore, in SSC movements there is the potential for the muscle fibers to be displaced less and thus be operating closer to an optimal length. Using the same reasoning, it is also feasible that the recoil of the tendinous structure would allow the velocity of shortening of the contractile element to proceed more slowly with a corresponding enhancement to force production due to the force-velocity characteristics of muscle contraction (Walshe et al., 1997).

With regard to the relative contribution of each of these six explanations, Bobbert et al. (1996) suggests that the greater achievement in CMJ compared with SJ is mainly due to the fact that the counter movement allows the extensor muscles to build up active state and force prior to shortening. In SJ, shortening starts as soon as the level of muscle stimulation is increased above that required for maintenance of the starting position and consequently less force and thus less work is produced over the first part of the shortening distance.

The possibility of poor coordination in the SJ was also ruled out as there was no movement disintegration i.e. the muscle forces were converted to whole body acceleration with efficiency equal to that of the CMJ (Bobbert et al., 1996).

There was no indication that muscle stimulation in CMJ was enhanced by neural responses triggered by the pre-stretch because the EMG levels during the start of the concentric phase were not different between the SJ and CMJ (Bobbert et al., 1996). This finding has been supported by Walshe et al. (1997) who found no difference in EMG activation between a concentric only and SSC movement. However, it is possible that EMG was facilitated during the eccentric phase thus contributing to the development of a high level of active state and muscle force before the start of push-off (Bobbert et al., 1996).

With regard to storage and reutilisation of elastic energy, Bobbert et al. (1996) argue that if the concentric angular displacement is the same, an increase in the amount of elastic energy stored at the start of the concentric phase merely reduces the amount of energy to be produced by the contractile elements. This is because lengthening of the series elastic elements occurs at the expense of the length over which the contractile elements can do work. Thus, stored elastic energy increases the efficiency of doing positive work, but not the total amount of positive work that can be produced.

Similarly, the role of stretch potentiation of the contractile machinery is thought to be minimal in CMJ. This is because the speed of pre-stretch must be high and immediately followed by the concentric phase. In the simulation study by Bobbert et al. (1996) speed of pre-stretch was

relatively low and a relatively long time delay (more than 200 ms) occurred between the end of pre-stretch and the point of maximal power production. In fact, most people who study reflexes concede that the force evoked during a stretch reflex is small and probably of minimal significance during high-force contractions (Prochazka, 1996).

Bobbert et al. (1996) did not address the issue of interaction between the contractile mechanics and the tendinous recoil (Ettema et al., 1992), however, Walshe et al. (1997) found that this mechanism was not a possible explanation for the differences in SSC and concentric only (CO) performance in their study.

In summary then, it would appear that the difference in CMJ and SJ height is due primarily to the fact that the countermovement allows the subject to attain greater joint moments at the start of the upward movement. This results in greater forces exerted against the ground and subsequently an increase in impulse ( $F \times t$ ) and thus acceleration of the whole body upward. The other mechanisms proposed appear to play at best a secondary role in the enhancement of performance by the SSC.

Studies by Bosco and Komi (1979) demonstrate that performance increases with increasing stretch loads applied. For example, during “drop jumping”, the height of the subsequent jump increases with increases in drop height. This occurs only up to a point. They suggested that there is a threshold at which the stretch load is too great and the Golgi tendon organ reflex may cause an inhibition of muscle action reducing the jump height attained (Gollhofer and Kyröläinen, 1991; Schmidtbleicher et al., 1988). It should be noted that athletes unaccustomed to intense SSC loads may produce his or her best performance during a CMJ, and the drop jump heights will be even lower than the SJ (Schmidtbleicher, 1992). This may be because the inhibition effect of the Golgi tendon organ reflex is relatively strong (i.e., has not been modified through prior SSC training) limiting SSC performance (Schmidtbleicher, 1992).

It is important to note that such discussion, although accepted in the strength and conditioning literature, may present a far too simplistic interpretation of the role of the Golgi tendon organs and spinal reflex mechanisms. A recent paper by Prochazka et al. (1997) actually reports positive force feedback from the tendon organs during locomotion. Further, it has been demonstrated that tendon organ afferent output results in activation or inhibition of the muscles involved in the movement with the effect varying with muscle group, role (agonist, antagonist, synergist), and side of the body (Pratt, 1995).

A possible explanation for the increased jump height with increased drop height is the extensor muscles may build up greater force prior to shortening action when landing from a jump.

Similarly, the reduced jump height in a drop jump (DJ) compared with CMJ for athletes unaccustomed to drop jumps may be due precisely to their lack of experience. That is, they produce lower jumps when dropping down from a height simply because they cannot apply optimal control of the movement because they have not learnt the skill.

### **Effects of Training on SSC Performance**

Maximal power performance has been shown to respond to training, which involves the athlete performing SSC movements with a stretch load greater and more rapid than to which they are accustomed. These activities have been termed “plyometrics” and have been found, in a number of studies, to be effective for increasing jumping ability (Adams et al., 1992; Clutch et al., 1983; Schmidtbleicher et al., 1988; Wilson et al., 1993). According to Schmidtbleicher et al. (1988), plyometric training results in an increase in the overall neural stimulation of the muscle and thus force output, however, qualitative changes are also apparent. In subjects unaccustomed to intense SSC loads, some studies have reported a reduction in EMG activity starting 50-100 ms before ground contact and lasting for 100-200 ms (Schmidtbleicher et al., 1988). Gollhofer (1987) has attributed this to a protective mechanism by the Golgi tendon organ reflex acting during sudden, intense stretch loads to reduce the tension in the tendo-muscular unit during the force peak of the SSC. After periods of plyometric training the inhibitory effects are reduced, termed disinhibition, and increased SSC performance results (Schmidtbleicher et al., 1988). However, it should be pointed out that this mechanism remains highly speculative and no conclusive research has been presented to date.

Plyometric training places considerable forces on the musculo-skeletal system and it is recommended that the athlete have a preliminary strength training base prior to commencing a plyometric training program (e.g., squat 1.5 times body weight)(Chu, 1992) for reasons previously explained. The potential for injury is thought to be much higher for drop jumps and should not be attempted by the beginner (Schmidtbleicher, 1992).

As previously discussed, strength training results in increases in vertical jump performance in both trained and untrained subjects (Häkkinen and Komi, 1985a; Wilson et al., 1993; Wilson et al., 1997). Two notable simulation studies have gained further insight into the mechanisms underlying this performance enhancement (Bobbert and Van Soest, 1994; Pandy, 1990). Perhaps the most convincing explanation for the difference between CMJ and SJ height is that the force at the start of the concentric phase in the CMJ is maximal while for the SJ it is zero (explanation 2 above). Therefore, if maximum strength in this position can be increased then greater vertical force is exerted and impulse is increased resulting in greater takeoff velocity and subsequent jump height.

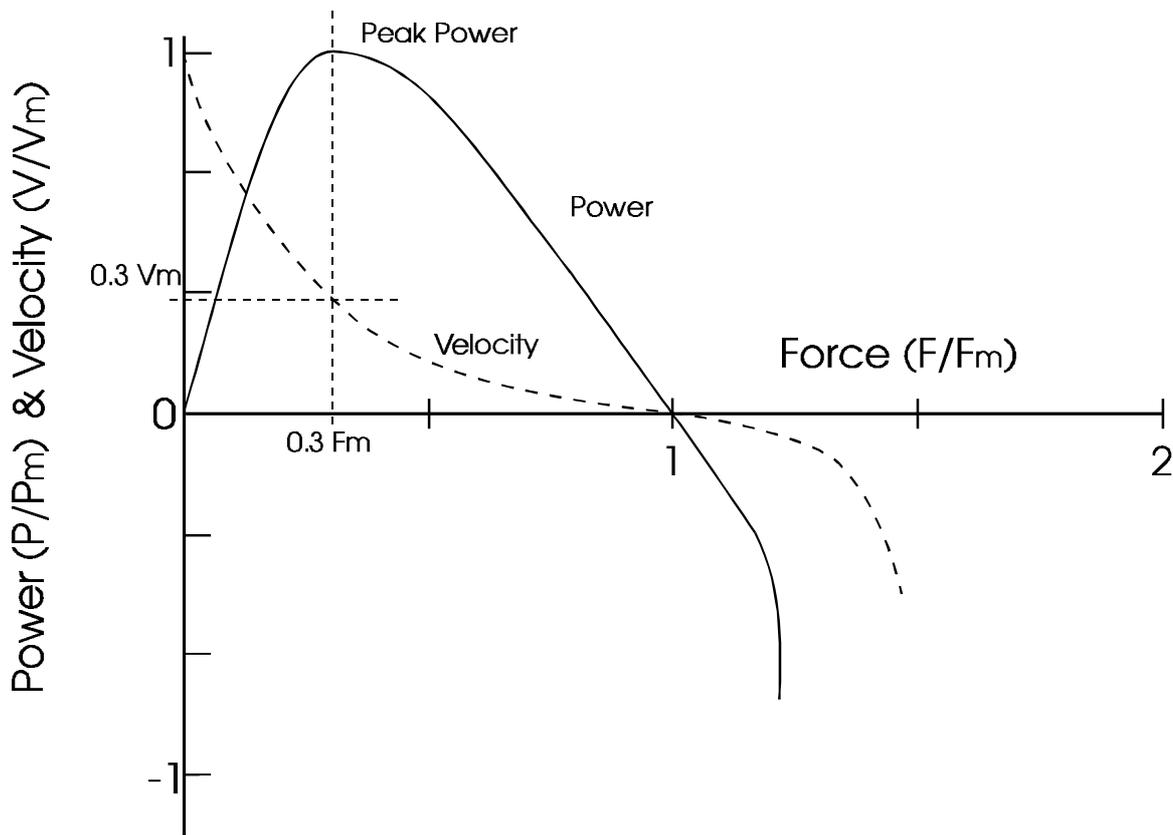
SJ height is also increased for the same reason as a result of increased muscle strength.

## **Aspects of Training to Increase Maximal Power**

### ***Muscular Strength and Heavy Resistance Training***

Strength is the ability of the muscle to exert a maximal force or torque at a specified or determined velocity (Knuttgén and Kraemer, 1987) and varies for different muscle actions such as eccentric, concentric, and isometric (Kraemer, 1992). Often coaches and athletes associate the term strength only with the force, which can be exerted during slow speed or even isometric muscle actions. This is often determined using a 1 repetition maximum (1RM) test in which strength is assessed as the maximum weight the athlete can lift once through the complete movement. The development and assessment of 1RM strength has received a great deal of research attention and the interested reader may refer to the relevant literature (Atha, 1981; Berger, 1962; Häkkinen, 1989; Schmidtbleicher, 1988). When lifting the maximal weight that the athlete is capable of, the limiting factor is muscle strength at slow contraction velocities. Muscle strength as required in 1RM lifts, however, is a requirement of a limited number of athletic endeavours (e.g., Power Lifting) with most sports requiring high force output at much faster velocities of movement.

From an athletic perspective it may be more appropriate to think of strength as the force capability of the muscle for actions ranging from the fastest eccentric to the fastest concentric. Examining the force velocity relationship for muscle (Figure 2.2), it dictates that the faster the velocity of concentric muscle action, the lower the force that can be produced (Hill, 1938). The decline in force with increasing velocity of muscle contraction may be attributed to a loss of force due to the internal resistance, which develops during high speed contractions (Hill, 1938). Because a muscle's force potential is proportional to the number of active sarcomeres in parallel and its velocity potential is proportional to the number of active sarcomeres in series, sarcomere arrangement must influence the power potential of different muscles and muscle groups at varying velocities of shortening (Edgerton et al., 1986). It has, however, been consistently observed that maximal concentric power is produced at intermediate velocities of movement (approx. 30% of maximum shortening velocity) (Kaneko, et al., 1983). Pure 1RM strength is required in the sport of Power Lifting (name of sport is inappropriate) because there is no requirement for the weight to be moved quickly (low velocity demands) as the athlete is attempting to lift the maximum amount of weight. This requires movement velocities which are just higher than zero. Thus, one exhibits maximal force but relatively low levels of power in the 1RM lifts.



**Figure 2.2** Force velocity power relationship for skeletal muscle.  $V_m$ ,  $P_m$  and  $F_m$  are maximum movement velocity, maximal power output and maximum isometric force output respectively (adapted from Faulkner et al., 1986).

Previous research (Häkkinen and Komi, 1985a; Wilson et al., 1993; Wilson et al., 1997) and anecdotal evidence from strength and conditioning specialists report that if an athlete's strength at slow movement velocities increases, then power output and athletic performance also improve. This is true because maximum strength, even at slow velocities, is a contributing factor in maximal power. When attempting to maximise power output, the concentric phase follows the eccentric phase and as such starts from a zero velocity. Therefore, the force produced during the later part of the eccentric phase, the changeover from lengthening to shortening which includes a period when the muscle is contracting isometrically, and the subsequent concentric contraction is determined by the maximum strength of the agonist muscles during slow eccentric, isometric and concentric contraction. If maximal strength is increased then higher forces can be exerted during this period resulting in increased impulse and therefore increased acceleration. Bobbert and Van Soest (1994) have demonstrated the effect of an increase in muscle strength in a simulation study and have shown increases in vertical jump height.

However, as the muscles begin to achieve high velocities of shortening, strength capacity at slow movement velocity has a reduced impact on the ability of the muscle to produce high force at rapid shortening velocities (Duchateau and Hainaut, 1984; Kanehisa and Miyashita, 1983; Kaneko

et al., 1983). This fact becomes increasingly important as the athlete attempts to specifically train for maximal power development.

In terms of training, several studies have shown improved performance in power activities (e.g. vertical jump) following a strength training program (Adams et al., 1992; Bauer et al., 1990; Clutch et al., 1983; Wilson et al., 1993). For example, research by Häkkinen and Komi (1985a) showed a 7% improvement in vertical jump following 24 weeks of intense weight training.

Schmidtbleicher and Haralambie (1981) found significant increases in muscle strength and faster contraction times resulting from 8 weeks of heavy resistance training. The authors postulated that the use of heavy loads required the activation of the fast twitch muscle fibers according to the size principle of motor unit recruitment (Sale, 1992). As such, the fast twitch muscle fibers of the trained muscles exhibited adaptations resulting in improved contraction and half-relaxation times. It has been demonstrated that the force per cross sectional area of Type I and Type II muscle fibers is similar, however, the peak power output of Type II fibers is fourfold that of Type I fibers (Faulkner et al., 1986). Interestingly, more recent work (Harridge et al., 1996; Harridge et al., 1998; Larsson, et al., 1996) has revealed for the first time, that the specific tension of muscle fibers varies across fiber type and as a function of altered levels of physical activity. Therefore a further mechanism for increased power output from slow velocity, heavy resistance strength training lies in the activation and subsequent training adaptation of the fast twitch fibers.

In a study by Häkkinen and Komi (1985b), a group of subjects performed movements in which they attempted to maximise power output with relatively lighter loads and produced significant improvement (mean 21% increase) in vertical jump. The results indicated that there might be specific training adaptations to heavy resistance versus power-type training. Heavy resistance strength training using high resistance and slow velocities of concentric muscle action leads primarily to improvements in maximal strength (i.e., the high force/low velocity portion of the force-velocity curve (see Figure 2.2)) and the improvements are reduced at the higher velocities. In power training, which utilizes lighter loads and higher velocities of muscle action, there are resulting increases in force output at the higher velocities as well as the rate of force development (Häkkinen and Komi, 1985b).

Although velocity specific training adaptations are observed, performance changes with training are not always consistent with this principle. The conflict results from the complex nature of powerful muscle actions and the integration of slow and fast force production requirements within the context of a complete movement. Another confounding influence in observing clear, specific training adaptations is the fact that in untrained people, a wide variety of training

interventions will produce increases in strength and power. Komi and Häkkinen (1988) suggest that depending on the training status of the individual, the response may not always follow the velocity specific training principle. For individuals with low levels of strength, improvements throughout the force velocity spectrum may be produced regardless of the training load or style used (Komi and Häkkinen, 1988). A further avenue for improvement in untrained subjects is the relatively high RFD's which can be achieved with heavy weights or even isometrically when the subject has the "intention of making fast movements" (Behm and Sale, 1993a). This may contribute to adaptations particularly in those unfamiliar with trying to make fast contractions.

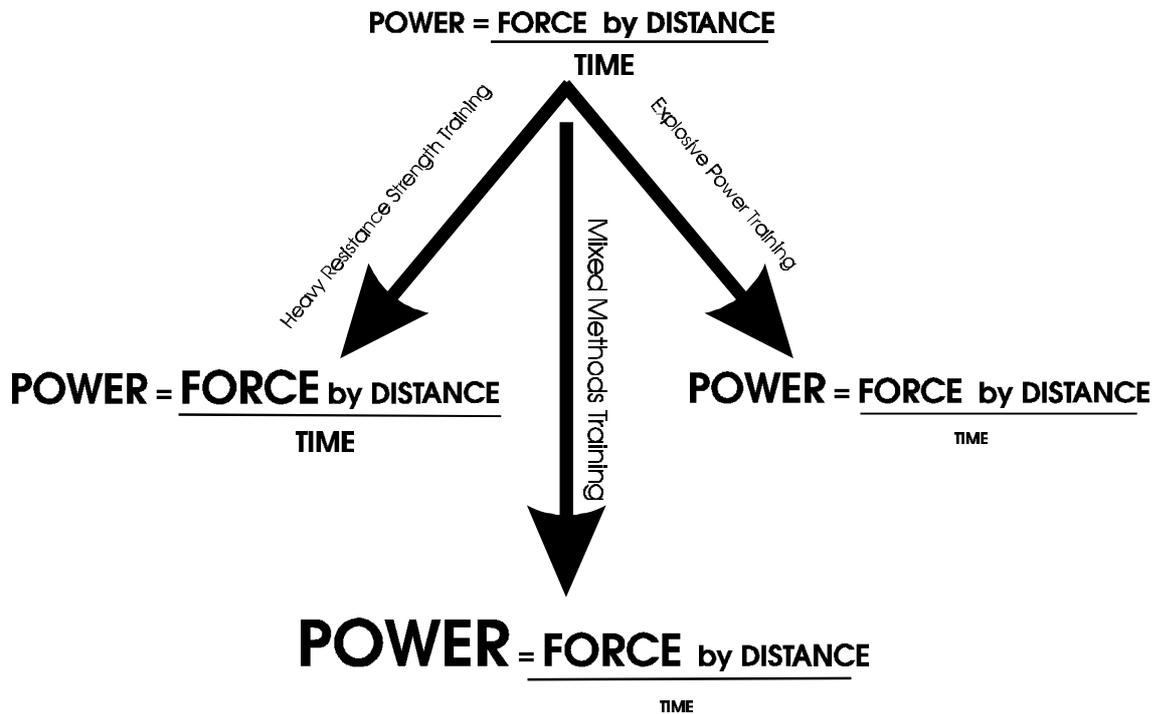
It appears that training adaptations of single factors (i.e., high force, high power) occur only after a base level of strength and power training has been undertaken. This is supported by the fact that if the athlete already has an adequate level of strength, then the increases in maximal power performance in response to traditional strength training will be poor, and more specific training interventions are required to further improve maximal power output (Häkkinen, 1989). Thus, improvement of maximal power output in trained athletes may require more complex training strategies than previously thought (Wilson et al., 1993).

This contention is supported by further research by Wilson, Murphy and Walshe (1997) who compared the changes in 1RM squat, vertical jump, and flying 20 m sprint velocity during 8 weeks of weight training or plyometric training. Subjects were classified as weak or strong based on their pre-training 1RM squat. The results demonstrated significant negative relationships between weight training induced improvements in sprinting, jumping and pre-training 1RM performance. The authors hypothesized that this was due to the principle of "diminished returns" whereby initial improvements in muscular function are easily attained, however, further improvements are progressively harder to achieve. Unexpectedly, the performance gains from the plyometric training were unrelated to initial strength levels.

### ***A Need for Training Integration***

The use of slow velocity, heavy resistance training for the development of maximal power is often justified based on the fact that power is equal to force times the velocity of the muscle action. It has often been reasoned that if the athlete increases his or her 1RM strength then this is all, which is required from a resistance training program. However, if we are to maximize improvements in power performance, then we must train both the force **and** velocity components. This concept is summarized in Figure 3. Because the movement distance is usually fixed by the athlete's joint ranges of motion, velocity is determined by the time taken to complete the movement. Therefore, if we train using methods which will decrease the time over which the movement is produced, we

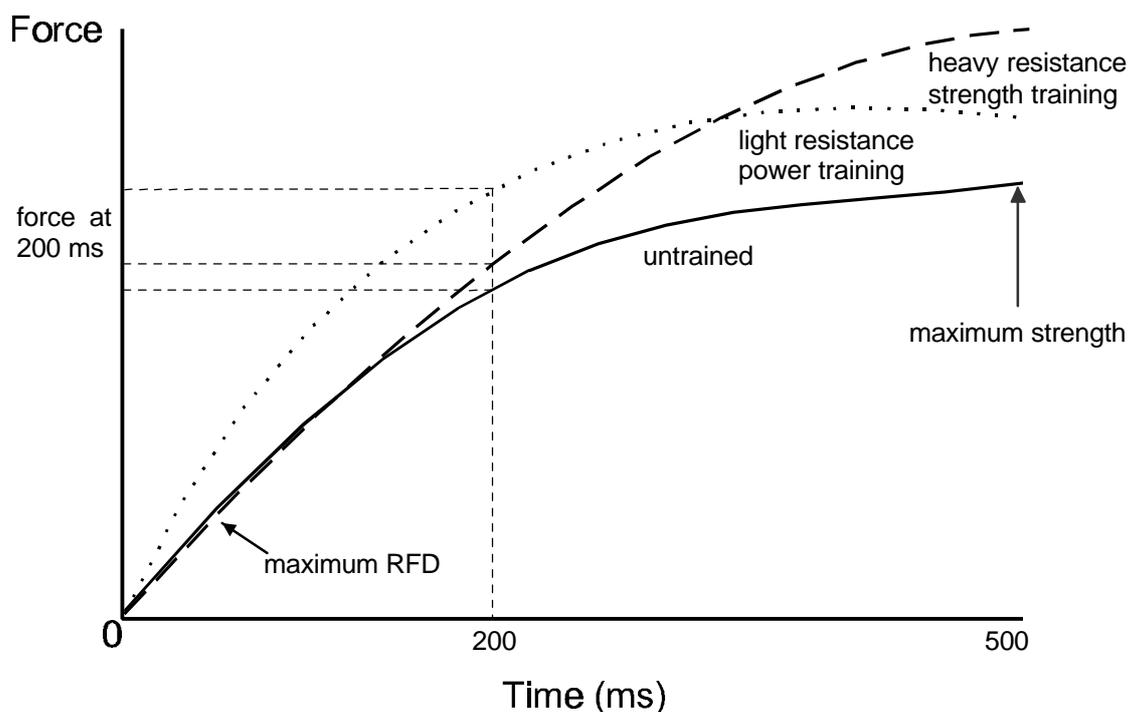
increase the power output. Intimately linked to this concept is the maximum rate of force development (mRFD).



**Figure 2.3** Diagrammatic representation of the relationship between force, velocity and power. Velocity has been expressed as displacement over time. The size of the words indicates the relative capacity of the athlete for each factor and the response of these factors to various forms of training.

### ***Resistance Training and Rate of Force Development***

Because time is limited during powerful muscle actions, the muscle must exert as much force as possible in a short period of time. One factor contributing to this has been termed the mRFD (Figure 2.4). This may explain to some extent why heavy resistance training has been ineffective for increasing power performance. Squat training with heavy loads (70%-120% of 1RM) has been shown to improve maximum isometric strength (i.e. movement velocity = zero), however, it did not improve the maximum rate of force development (Häkkinen et al., 1981) and may even reduce the muscle's ability to develop force rapidly (Häkkinen, 1989). On the contrary, an activity during which the athlete attempts to develop force rapidly (e.g., maximal power jump training with light loads) increases an athlete's ability to increase force output at a fast rate.



**Figure 2.4.** Isometric force-time curve indicating maximum strength, maximum rate of force development and force at 200ms for untrained, heavy resistance strength trained and light resistance, power trained subjects (adapted from Häkkinen and Komi, 1985a; Häkkinen and Komi, 1985b).

Specifically, maximal power type resistance training which increases the slope of the early portion of the force time curve which has been termed the maximum rate of force development (mRFD)( Häkkinen and Komi, 1985b). Figure 2.4 compares the effects of heavy resistance training versus maximal power training on the isometric RFD curve. Although heavy resistance training in this study increased maximum strength and thus the highest point of the force-time curve, this type of training did not improve power performance appreciably, especially in athletes who have already developed a strength training base (i.e., more than 6 months of training)(Häkkinen, 1989). This may be because the movement time during powerful activities is typically less than 300 ms (Young, 1993) and most of the force increases cannot be realized over such a short period of time. The athlete does not have the time to utilize the strength gains at slow movement velocities, which they have achieved through heavy resistance training.

Schmidtbleicher expresses an alternate view in several papers (Schmidtbleicher and Haralambie, 1981; Schmidtbleicher and Buehrle, 1983; Schmidtbleicher, 1992). As discussed previously, the lifting of heavy loads requires activation of the fast twitch muscle fibers and their subsequent adaptation towards increased size and increased concentration of contractile enzymes Schmidtbleicher argues should lead to an increased mRFD. Whether this mechanism still applies in already strength trained subjects is not known.

Even the measurement mRFD and its predictive ability in terms of athletic performance have been questioned. Earlier research has determined mRFD during isometric muscle contractions because this alleviates the problems of the changing muscle length, which accompanies dynamic contractions (Häkkinen, Alén, and Komi, 1985). However, Murphy et al. (1994) reported a poor correlation between measures of dynamic performance and isometric mRFD. The authors suggested that neural and mechanical differences between dynamic and isometric muscle actions limit the application of isometric test results to athletic performance. This is in contrast to suggestions that isometric mRFD represents a measure of basic neuromuscular function and as such should be indicative of performance in all movements in which power is maximised (Häkkinen, 1989; Schmidtbleicher, 1988, 1992). Given that in almost all movements where the intention is to maximise power output, a SSC is performed, determination of mRFD during the eccentric phase might yield more realistic measures (Murphy et al., 1994). Further research in this area is certainly warranted.

### ***The Controversy of Velocity Specific Training***

Velocity specificity of resistance training is currently one of the most contentious issues in the field of muscle strength and power development. Studies using isokinetic testing and training methods have found that strength increases are specific to the velocity at which one trains (Lesmes et al., 1978). If you train at a slow movement velocity you tend to increase strength at that velocity and strength at higher velocities, which are more common in sport, is not effected. Based on this, it has been recommended that resistance training be performed at a high speed if the purpose of the training is to increase power output.

Behm and Sale (1993a) have presented evidence that it is the **intention** to move quickly which determines the velocity specific response, and that heavy resistance weight training may be effective if the athlete attempts to move the resistance as quickly as possible. Eight men and eight women trained 3 days/week for 16 weeks performing attempted ballistic unilateral ankle dorsiflexions against resistance, which either rendered the resultant contractions isometric (one limb) or allowed a fast isokinetic (5.23 radians/s) movement (other limb). At each training session 5 sets of 10 repetitions of each type were completed. Training produced the same high velocity specific changes in both groups. Specifically, peak torque increased most at 5.23 radians/s (38%) in comparison to the slower velocities tested. Both limbs showed similar increases in voluntary isometric rate of torque development (26%) and relaxation (14%) and in evoked tetanus rate of torque development (14%). Behm and Sale (1993a) concluded that all of these training induced changes previously associated with high velocity resistance training were produced by a training regimen, which prevented actual rapid movement. This was the basis for their contention that the

principal stimuli for the high velocity training response are the repeated attempts to perform ballistic contractions and the high rate of force development of the ensuing contraction. The type of muscle action (isometric or concentric) appeared to be of lesser importance.

This theory has also been tested in a study by Young and Bilby (1993) who compared the effects of slow and fast weight training on vertical jump and rate of force development. This study failed to find a velocity specific effect on rate of force development and contrary to their alternative hypothesis, in fact the slow weight training was more effective for increasing vertical jump performance. However, the subjects had no prior weight training experience and this may have influenced the results as both groups exhibited marked adaptations to what was a novel stimulus to untrained subjects perhaps masking any differential effects of training velocity.

Kaneko et al. (1983) found velocity specific effects for a task which involved lifting a weight as quickly as possible. Subjects trained with a resistance of 0%, 30%, 60% or 100% of maximum isometric strength. The results demonstrated a classic resistance-specific training effect. The groups training with the heavier resistances produced the greatest increases in isometric strength and the group training with 0% resistance produced the greatest increase in unloaded movement velocity. Perhaps the most interesting finding was that the 30% resistance produced the greatest increase in force and power over the entire concentric velocity range and also resulted in the greatest increase in maximum mechanical power.

Certainly, further research is required. Based on studies of muscle fiber contractile characteristics (Faulkner et al., 1986; Green, 1986) there appears to be a great range of adaptations within the cell which alter its maximum velocity of shortening and force output at specific velocities. In particular, a considerable difference exists in the power capacity of fast twitch (Type II) versus slow twitch (Type I) muscle fibers (Faulkner et al., 1986) which will be discussed in detail in the next section.

One study by Duchateau and Hainaut (1984) removed the confounding variable of neural innervation and only considered contractile changes within the muscle. Subjects completed 12 weeks of training using either voluntary dynamic contractions with a resistance of 30% of maximum voluntary contraction (MVC) or isometric contractions of the adductor pollicis muscle. Both groups were tested using electrically stimulated contractions against 6 loads ranging from 0% to 100% of MVC. The dynamically trained group produced increases in maximum contractile speed (0% load) whereas the isometrically trained group did not but rather increased velocity in conditions of higher mechanical resistance. The authors noted that speed of movement for small loads is essentially related to the rate of rise of force development (mRFD) whereas for heavy loads

it is closely related to maximal force capability. Both types of training were seen to augment muscle power for different loads, but the peak power increase after isometric training was higher than the peak power increase after dynamic training (51% vs. 19%). Furthermore, only isometric training shifted the muscle optimal power peak towards heavier loads. Duchateau and Hainaut (1984) speculated that the isometric training produced increases in muscle cross-sectional area resulting in increased maximal force. The dynamic training may have increased myosin ATPase activity and/or calcium release from the sarcoplasmic reticulum. Also, the quantity and/or quality of the sarcoplasmic reticulum may have been improved. Whether the actual shortening velocity of the muscle fiber or the frequency of neural input is the stimulus to these adaptations in force production at specific velocities remains speculative.

### ***The Optimal Resistance for Producing Maximal Power Output***

Several studies (Kaneko et al., 1983; Moritani et al., 1987; Wilson et al., 1993) have recommended that to increase maximal power output, athletes should train at the velocity and using the resistance which maximizes mechanical power output. As can be seen from Figure 2.2, the concentric force and velocity capabilities of muscle are intimately linked. Maximal mechanical power is produced at a resistance of 30% of maximum isometric strength which corresponds to a velocity of muscle shortening of approximately 30% of maximum (Faulkner et al., 1986).

A study by Wilson et al. (1993) compared the effects of 10 weeks of training using traditional back squats, loaded jump squats or plyometrics in the form of drop jumps on vertical jump performance. The loaded jump squats were completed using a resistance, which allowed the subjects to produce the greatest mechanical power output. All the training groups produced increases in vertical jump performance, however, the maximal power group produced significantly greater increases (18%) than the other two groups (heavy resistance training, 5%; drop jump training, 10%). These results were similar to that obtained by Berger (1963) who also found that performance of jump squats with a resistance of 30% of maximum, resulted in greater increases in vertical jump as compared with traditional weight training, plyometric training or isometric training.

The studies by Wilson et al. (1993) and Berger (1963) found superior improvements in power performance resulting from jump squat training using a 30% resistance as compared with heavy squat lifting. This may not have been a reflection of the resistance used but rather the more specific training movement of jump squats and the disadvantages of traditional weight training movements which will be discussed next.

Heavy resistance training will increase power output at low velocities and heavy resistances, while light resistance training (e.g. 30% MVC) will increase power output for light resistances

(Duchateau and Hainaut, 1984). Further, heavy resistance training tends to shift the optimal resistance for power output towards the heavier resistances (i.e. maximal power output is produced at a heavier resistance).

Therefore, increases in power are specific to the training resistance and velocity used. This may be the rationale behind the recommendation of a 30% MVC resistance. As this is the resistance at which power is maximized, training at this resistance will necessarily produce the greatest increases in maximal power. However, the degree to which this increase in power output will transfer to athletic performance, may depend on whether the mass being moved represents a similar resistance to 30% MVC. Accelerating the leg to kick a football or throwing a baseball represents a much lighter resistance than 30%.

Further research is required, however, it may be prudent to continuously adjust the resistance used in training to ensure increased power output at both slow and fast movement speeds. Also, the presentation of a range of loads and resulting movement speeds may be more effective due to the changing stimulus of the neuromuscular system eliciting greater adaptations. This concept remains speculative, however, and should be investigated.

### ***The Deceleration Phase and Traditional Weight Training***

The results of many studies (Berger, 1963; Wilson et al., 1993; Young and Bilby, 1993) highlight a further problem with traditional weight training and power development. It has been observed that when lifting a maximal weight in a bench press, the bar is decelerating for a considerable proportion (24%) of the concentric movement (Elliott et al., 1989). The deceleration phase increases to 52% when performing the bench press lift with a lighter resistance (e.g., 81% of 1RM)(Elliott et al., 1989). In an effort to train at a faster velocity more specific to sport activity, athletes may attempt to move the bar rapidly during the lift. This also increases the duration of the deceleration phase, as the athlete must slow the bar to a complete stop at the end of the range.

Plyometric training, weighted jump squats and the weightlifting movements avoid this problem by allowing the athlete to accelerate all the way through the movement to the point of projection of the load (i.e., takeoff in jumping, ball release in throwing, or impact in striking activities). It could be argued that traditional weight training promotes the athlete to develop this deceleration action. The deceleration results from a decreased activation of the agonists during the later phase of the lift and may be accompanied by considerable activation of the antagonists, particularly when using lighter resistances and trying to lift the weight quickly. It is not known if this inhibits the development of maximal power performance.

To the contrary, several researchers have reported considerable increases in maximal power output activities resulting from training programmes, which incorporate the traditional weight training movements. This has been observed in both previously untrained (Palmieri, 1987; Young and Bilby, 1993) and trained (Wilson et al., 1993) subjects suggesting that the deceleration phase may not limit improvements in maximal power. A possible mechanism for such improvement has been proposed by Schmidtbleicher (1992) that the repeated recruitment of fast twitch fibers through heavy resistance training leads to hypertrophy of these fibers and thus an increase in mRFD and maximal power output (Schmidtbleicher, 1992).

### ***Ballistic Resistance Training***

The problem of the deceleration phase can be overcome if the athlete actually throws or jumps with the weight. This has been termed “dynamic” (Wilson et al., 1993) or “explosive” (Häkkinen and Komi, 1985b) resistance training but is probably best described as “ballistic” resistance training. The term dynamic is not really applicable because all training which involves movement (i.e., not static or isometric) has been traditionally defined as dynamic. In addition, the term “explosive” is too general, as one can “attempt to explode” from the bottom of a traditional squat but reduce the effort near the top of the range of motion and never leave the ground as in the study by Young and Bilby (1993). Similarly, the training study by Behm and Sale (1993a) could be said to involve “explosive” muscle action but the joint movement was actually isometric. Further the term “explosive”, although frequently used in the coaching literature, cannot accurately describe human movement as in the strict sense of the word, no “explosion” occurs.

Ballistic infers accelerative, of high velocity and with actual projection into free space. The common English meaning of the word “ballistic” as defined in the Macquarie Dictionary (Delbridge and Bernard, 1988) is:

*“...of or pertaining to the motion of projectiles proceeding under no power and acted on only by gravitational force and the resistance of the medium through which they pass.”*

As projection of the load into free space such that it becomes a projectile is the essential aspect of this type of training which differentiates it from other forms, the term “ballistic resistance” training seems most appropriate.

### ***Heavy Versus Light Resistance***

Whether performing traditional or ballistic resistance training, there is considerable controversy over the resistance to be used for the development of maximal power performance

(Wilson et al., 1993; Young, 1993). If training is limited to traditional resistance techniques then heavy (>80%) resistances are preferable because it is not possible to overload the muscle sufficiently using light resistances while stopping the weight at the top of the range of motion (Hatfield, 1989). When using ballistic resistance there is perhaps no optimal intensity or resistance. Both heavy (>80%) and light (<60%) resistances have application in the training of muscular power, with each affecting different components of muscle power production. If the coach or athlete had to choose a single resistance, then the resistance which produces the greatest power output (30% MVC) has been shown to be optimal (Kaneko et al., 1983, Wilson et al., 1993). In reality, there is a wide selection of resistances, and greatest training adaptations will result when athletes train with resistances which span the concentric force velocity capability (Kaneko et al., 1983).

Although ballistic resistance training is effective for improving power performance, it does present the problem of the high forces exerted on the athlete when they land from the jump or catch the falling weight (Newton and Wilson, 1993a). However, weight training equipment can be adapted to reduce the forces experienced during the landing phase (Newton and Wilson, 1993a). In addition, it may be advisable for ballistic weight training to progress gradually from the unloaded to loaded conditions with the athlete having completed a prior strength training program. This is based on the recommendation in a position paper from the U.S. National Strength and Conditioning Association that prior to the performance of high intensity plyometric training an athlete should be capable of squatting at least 1.5 times body weight (Wilson et al., 1997), however, there is no research evidence to support or refute such a recommendation.

It does appear that there is a constant proportion of collagen and other non-contractile tissue, regardless of the muscle size or state of training. Thus, the absolute amount of connective tissue is considerably greater as a result of heavy resistance training compared with pre-training levels as the training-induced hypertrophy of muscle fibers is accompanied by a proportional increase in connective tissue (MacDougall, 1986). Within the muscle cell, endo- and exosarcomeric cytoskeletal proteins create series and parallel connections between contractile proteins resulting in a meshwork across which force can be transmitted in practically any direction with respect to the fiber axis onto the connective tissue matrix and thus to the tendons (Patel and Lieber, 1997). It could be postulated that adaptations in the cytoskeleton would have a protective effect in terms of injury from subsequent plyometric or ballistic resistance training.

To be prudent a preparatory phase for development of basic strength levels may be necessary before progression to ballistic training techniques as has been similarly recommended for plyometric training (Chu, 1992).

The reasons for completing a prior strength training programme are two-fold. First, strength training with heavy loads and thus slow movement velocity uses controlled movements to overload the musculoskeletal system and thus structural changes may result which increase the strength of these structures and thus prepare the body for the higher forces, which may be exerted during ballistic resistance training. It could be theorized that this would have a protective role in terms of injury prevention, however, this has not been positively demonstrated in the research literature. Second, several theories of periodisation (Bompa, 1990; Mateyev, 1972; Medvedyev, 1988) state that it is desirable to increase muscle size and maximal strength prior to entering a training phase directed at improving maximal power as the final increases in power performance will be greater. As there is a strong relationship between strength and power it has been suggested that one cannot have a high degree of power without first being relatively strong (Wilson et al., 1997). Once again, however, due to the difficulty of executing such long term training studies no scientific longitudinal training research has been published which confirm or deny this theory. However, a short term (8 week) training study has shown that the performance gains from a plyometric training program are unrelated to the subject's initial strength level (Wilson et al., 1997). The authors suggested perhaps conventional thought that an adequate baseline of strength should be established prior to undertaking plyometric training should be "liberalised to some degree".

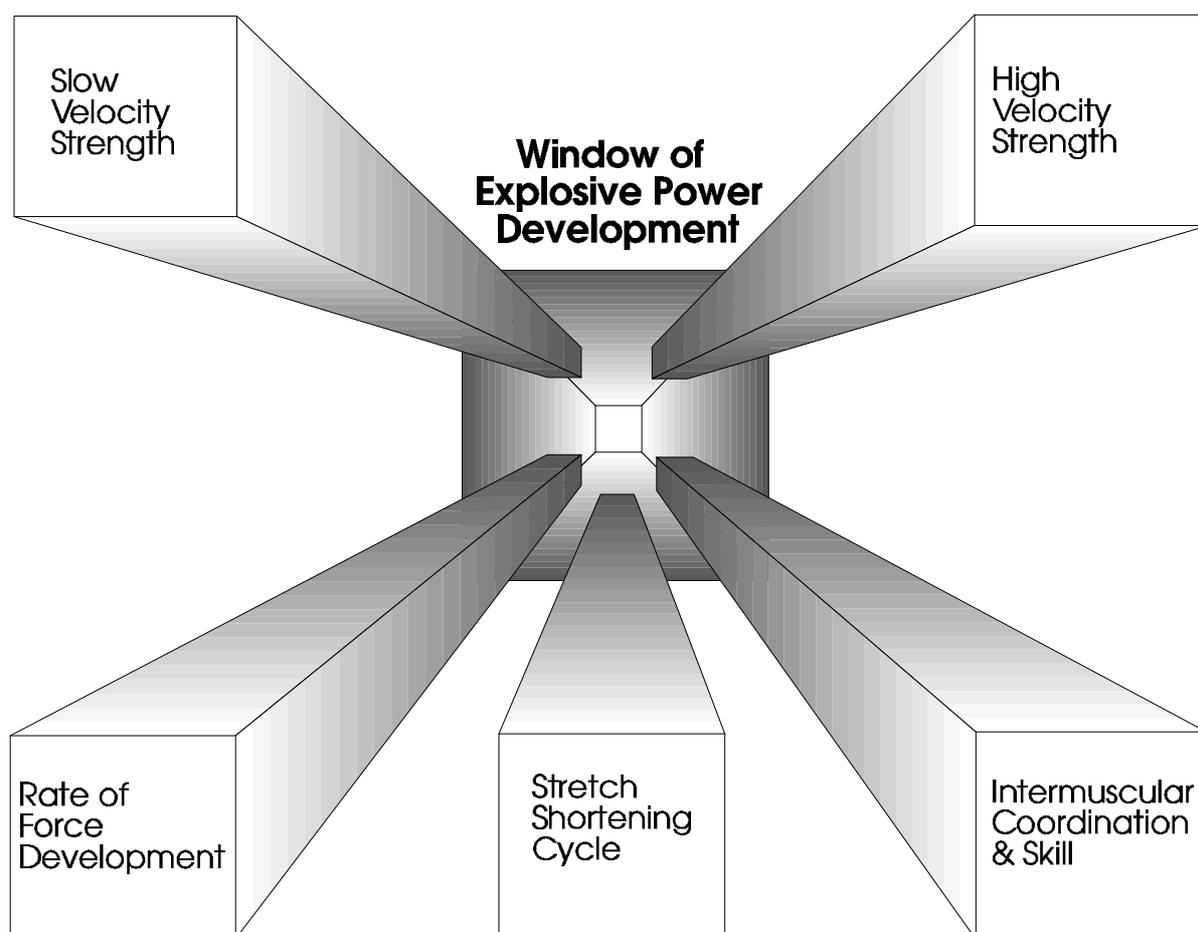
### ***The Window of Adaptation***

Several studies have compared the effectiveness of plyometric, resistance training, and a combination of plyometrics and resistance training. Although specific training protocols vary, in general, plyometric training alone has been shown to be effective for increasing power performance in both trained and untrained individuals (Adams et al., 1992; Clutch et al., 1983; De Brezzo et al., 1988; Duke and Ben Eliyahu, 1992; Holtz et al., 1988; Schmidtbleicher et al., 1988, Wilson et al., 1993). Traditional resistance training has resulted in increases in power output by the majority of the research (Adams et al., 1992; Bauer et al., 1990; O'Shea and O'Shea, 1989; Williams, 1991; Wilson et al., 1993; Young and Bilby, 1993) with a limited number of papers finding no change in already strength trained subjects (Häkkinen and Komi, 1985a; Komi et al., 1982).

When resistance training is combined with plyometrics, power output can be increased (Bauer, 1990; Blakey and Southard, 1987; Clutch et al., 1983) and this is perhaps a greater stimulus to maximal power production than either weight or plyometric training alone (Adams et al., 1992). These findings highlight the multi-faceted nature of power performance with a mixed training methods approach being most effective as it develops more components of muscle power. Further, the findings of Häkkinen and Komi (1985a; 1985b) demonstrate that as an athlete develops one component to a high level (e.g. strength) the potential for that component to contribute to further

increases in power output diminish. Thus, each component can be thought of as a “window of adaptation” to the larger window of adaptation in maximal power production. This concept is summarized in Figure 2.5.

The window of adaptation refers to the magnitude of potential for training adaptation. The principle of “diminishing returns” is described by Wilson, Murphy and Walshe (1997) as the observation that weight training is less effective at enhancing athletic performance as the strength level increases because such training is less effective at enhancing strength as initial strength levels increase. In a similar manner, an athlete who has undergone a programme of plyometric training will exhibit a shrinking window of adaptation to this form of stimulus. As this window shrinks, training time will be more efficiently spent on other training methods such as heavy resistance weight lifting or skills training. Further, training must be targeted to increase performance in those components in which the athlete is weakest, because here lies the largest window for adaptation and thus the greatest increase in maximal power production.



**Figure 2.5** Schematic diagram representing the components contributing to maximal power production. Each component can contribute to the overall window for power adaptation. The greater the development of a single component, the smaller that component's window of adaptation and thus potential to develop muscle power. Thus, it may be more efficient to design the training program to target those components with the greatest windows of adaptation i.e. the components in which the athlete is weak.

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### ***Effectiveness of Single Joint Exercises and Non-specific Exercises***

There is a belief among many strength and conditioning coaches that strength is a quality of muscle which can be expressed across all movements, which involve that muscle and that power will subsequently improve (Brzycki, 1986; 1988; 1991). As a result, training programs are often designed which utilize single joint exercises with low movement speeds, in the expectation that power output will be increased for the specific movement trained and this will carry over to more functional multi-joint movements.

It has been well established that strength development is specific to the movement pattern (Duchateau and Hainaut, 1984), speed (Kaneko et al., 1983; Lesmes et al., 1978), and type of muscle action (Kanehisa and Miyashita, 1983) used in the training. This is perhaps even more

evident when training for increased power (Häkkinen, 1989). There are, however, two possibilities for maximal muscle power in functional, multi-joint sport movements to be increased as a result of isolated, single-joint, slow velocity training:

Hypertrophy can be produced using a wide range of exercises, which involve the muscle and as cross-sectional area is increased the force capability of the muscle is greater regardless of the target movement. It has been speculated that hypertrophy is a result of training involving high volume of around 10RM resistance (Kraemer et al., 1996). Further, short rest periods between sets and exercises also promote hypertrophy because this results in a greater endocrine response (Kraemer et al., 1987), however, a direct link with muscle hypertrophy has yet to be established. A plausible explanation may be that the muscle size can be increased with resistance training using single-joint, non-specific movements and therefore strength will be increased as a result of the increase in muscle cross-sectional area. With sufficient coordination type training then this increased strength may contribute to increased power in more sport specific movements such as vertical jump (Bobbert and Van Soest, 1994).

Staron et al. (1994) has reported that changes occur in the contractile machinery within the muscle towards faster and more powerful characteristics. It could be theorised that these changes could then be generalised to movements other than that used in the training.

As has been discussed, much of the muscle's adaptation towards greater power development is neural in terms of better intra-muscular (mRFD) and inter-muscular coordination. As such, even if the above alterations are achieved through resistance training using movements, which are not specific, it is doubtful as to whether they can be effectively utilized in the target movement without additional training using movements specific to the target activity.

It is common in periodized training to undertake resistance training which is not specific to the athlete's sport but rather aims at overall increases in muscle size and strength, and then move onto more specific power training as the athlete approaches his or her competitive peak (Bompa, 1990). Further scientific research is required to determine if the gains from the previous more general strength training contribute to the performance developed while the athlete completes movement specific power training. That is, does the improved neural recruitment resulting from power training allow the athlete to take advantage of the local changes induced in the muscle during the preparatory phases?

An important consideration is that isolated joint exercises will produce increases in muscle strength and maximal power output of the trained muscle group, however, there may be a need to follow-up with further skill type training. This is required to develop the neural coordination

needed to utilise the improvements in muscle function for multi-joint movements such as vertical jump (Bobbert and Van Soest, 1994).

A further problem when trying to perform rapid single joint resistance training movements is the risk of injury. When the athlete rapidly accelerates the mass through the range of movement, considerable energy is stored in the form of motion of the implement or limb (i.e., kinetic energy). If the mass must stop at the end of the range, this energy must be absorbed by the muscles and joint structures over a very short period of time resulting in high forces being applied and an increased likelihood of injury. In ballistic resistance multi-joint training (e.g., loaded jump squats), the mass is released with high kinetic energy which is subsequently absorbed by the external environment. Therefore the momentum of the mass does not impact on the involved joints and muscles to the same extent.

### ***The Olympic Lifts***

The Olympic-style (snatch, clean and jerk) and related (hang pulls, hang cleans, power snatch, power clean, push press, power jerk) lifts have been proposed as effective exercises for the development of maximal power (Armstrong, 1993; Garhammer and Gregor, 1992; Garhammer, 1993). This training method has received wide acceptance because of the observation that weight lifters, on average, exhibit exceptional power output during vertical jump and sprinting (Garhammer, 1993). It could be argued that this is a result of genetic predisposition rather than Olympic-style training per se, however, there are several aspects to Olympic style lifting which make it particularly suitable for power development.

During Olympic weightlifting power output is extremely high, the speed of movement is fast and has an accelerative velocity profile making it much more specific than traditional resistance training exercises to maximal power performances in other sport activities (Garhammer and Gregor, 1992; Garhammer, 1993). This author could find only one longitudinal training study, which specifically examined the effects of Olympic style weightlifting on maximal power performance. This study demonstrated positive effects of Olympic style weightlifting on vertical jump performance (Stone et al., 1980).

Stone and colleagues (1980) trained 13 healthy males who had previous resistance training experience but no previous experience training as an Olympic weightlifter. Initially the subjects completed a two-week period of technique instruction to ensure that each subject could perform the snatch and clean lifts correctly. The subjects then completed squats,  $\frac{1}{4}$  squats, snatch, and clean pulls, three days per week for 14 weeks. At the completion of the training period the subjects had improved vertical jump height and power output by 8.8% and 4% respectively. Further, there were

strong correlations between vertical jump performance and snatch and clean performances and these correlations became stronger over the 14 weeks as the snatch and clean performances improved.

Many antagonists have inappropriately argued that such lifts are inherently more dangerous and that single joint exercises can accomplish the same effect. However, it can be seen from the available literature that both the injury (Hamill, 1994) and effectiveness arguments (Yessis, 1994; Yessis, 1995) fall short.

### ***Musculoskeletal Injury and Maximal Power Training***

Plyometric and ballistic resistance training involve the union between strength and speed using muscular contractions, which are characterised by SSC movements (Chu, 1992; Radcliffe and Farentinos, 1985). In particular, plyometric training involving dynamic SSC movements has become a popular training modality for many athletes as it enables the development of high force production over a short period of time (Adams, 1986; Adams et al., 1992; Chu, 1992). This is achieved by utilising exercises such as depth jumps, exaggerated hops, bounds, and box drills. Both plyometric and ballistic resistance training regimes offer several advantages over the more traditional forms of resistance training. As discussed previously, plyometric and ballistic movements are performed much more powerfully enabling the athlete to rapidly develop force (Häkkinen et al., 1985) and mimic the actual athletic performance by the use of dynamic SSC movements (Adams et al., 1992; Bosco et al., 1982; Schmidtbleicher et al., 1988; Thomas, 1988).

Despite the advantages of such training over other recognised training modalities, problems may arise with this type of exercise with regard to repetitive impact loading or excessively high eccentric impact forces. As a consequence of performing plyometric type exercises, such as depth jumps, or ballistic resistance training in the form of loaded jump squats, impact forces placed on the musculoskeletal system during landings can lead to a potential for injury (Dufek and Bates, 1990; Nigg et al., 1981; Scott and Winter, 1990).

Typically, the performance of maximal power exercises requires the musculature and joint mechanisms involved in the landing process to dampen the impact forces placed on the body. However, it has been reported that the musculo-skeletal system may be particularly vulnerable to the large increases in force which occur over the first 50 to 75 ms after initial ground contact on landing (Devita and Skelly, 1992; Nigg et al., 1981). This initial rapid rise in the vertical ground reaction force has possible implications for injuries to the lower limbs related to landings (Munro et al., 1987; Ricard and Veatch, 1990). The injuries associated with the lower limbs as a result of impact landings appear to be related to cartilage degeneration (Radin et al., 1973), fatigue fractures, shin splints (Andreasson and Peterson, 1986) and achilles tendon problems (Joergensen, 1985).

The initial impact forces, which occur within this 50 ms time frame of landing can be quantified by calculating the impact impulse (Bosco et al., 1983; Ricard and Veatch, 1990). It is this impact impulse, which has been speculated to result in injuries to the musculature and skeletal systems (Ricard and Veatch, 1990). The impact forces, which the body sustains from landing, appear to be influenced by the inter-relationship between several mechanical parameters. The height of the jump (Dufek and Bates, 1990; Stacoff et al., 1988) and the loading applied to the body (Fredrick and Hagy, 1986; Gollhofer and Kyröläinen, 1991; Scott and Winter, 1990) can be directly related to the velocity at impact (Devita and Skelly, 1992; McNitt-Gray, 1991; Munro et al., 1987; Valiant and Cavanagh, 1983). Subsequently it is the momentum attained prior to ground contact which influences the impact loads upon landing (McNitt-Gray, 1991). Landing technique (Fredrick and Hagy, 1986; Scott and Winter, 1990; Steele, 1989) has also been shown to effect the impact forces. It has been documented that stiff legged landings produce higher impact forces than landings which attempt to dampen the movement with hip and knee flexion (Devita and Skelly, 1992; McNitt-Gray, 1991; Zatsiorsky and Prilutsky, 1987).

Although one of the desirable adaptations of the neuromuscular system to plyometric training is that greater eccentric stretch loads can be tolerated (Schmidtbleicher et al., 1988) a problem arises as to how to progressively expose the body to increased stretch loads without excessive impact forces producing injury. Similarly, when performing ballistic resistance training, the body must absorb large forces to which it is not accustomed due to the extra loads used and the dynamic nature of the landing.

As discussed earlier, injury risk has been raised frequently by opponents of the use of weightlifting, plyometrics and ballistic resistance training for the development of athletic performance (Bryzicki, 1986, 1988, 1991). However, this author could find no studies, which substantiate these claims. Hamill (1994) has completed the most extensive study of injury rates in weightlifting and resistance training. The final conclusion was that weightlifting and resistance training are both very safe activities, when competently supervised. Two further points were raised which are relevant to the current discussion. The skills required in resistance training and weightlifting in particular, are complex and as such require a high level of supervision by knowledgeable coaches. Second, these skills should be taught with light loads first and then the participants should progress to higher intensities.

Although no research has examined injury rates for plyometric and ballistic resistance training one would expect that if the activities are well supervised and the participants begin the programme at a low intensity and then progress gradually, the injury risk should remain well below that of most sports.

## **Maximal Power Production of the Upper Body**

Many sport and work activities require high power output from the upper body. Although maximal power has been extensively studied in lower body activities such as vertical jumping (Bosco and Komi, 1979; Häkkinen et al., 1986; Häkkinen and Komi, 1985a; Häkkinen and Komi, 1985b; Komi and Bosco, 1978; Komi, 1984; Schmidtbleicher and Buehrle, 1983; Wilson et al., 1993; Young and Bilby, 1993), there is a paucity of research examining such movements in the upper body (Bober et al., 1980; Gollhofer et al., 1987; Van Leemputte et al., 1983). In particular, the influence of the stretch shortening cycle (SSC) in upper body movements has received limited attention (Bober et al., 1980; Elliott et al., 1989; Gollhofer et al., 1987; Van Leemputte et al., 1983).

Bober et al. (1980) have examined SSC movements in the upper body, however, this study increased the stretch load on the muscle by increasing the velocity of a swinging pendulum. The subject had to brake the pendulum and then push for maximal power against the same load. Similar stretch shortening cycle potentiation of performance was found for this upper body movement as has been measured for the lower body (Bosco and Komi, 1979). Gollhofer et al. (1987) have investigated the effects of fatigue on SSC performance of the elbow extensors. Both purely concentric and SSC test movements were performed, however, the resulting performances of each were not compared.

## **Maximal Power Production in the Aging Human**

As previously described in detail, human muscle is composed of two broad categories of muscle cells (fibers). The slow twitch fiber is characterised by high endurance, but slow rate of force production and low power output. In contrast, the fast twitch fibers possess low endurance, but a fast rate of force production and high power output. Slow twitch fibers are innervated regularly by normal daily activity; however, the fast twitch fibers are used only during muscle contractions requiring high force or rapid movement. In the aged there is a selective disuse atrophy of the fast twitch fibers (Evans and Campbell, 1993; Lexell and Downham, 1992) which is most likely a result of physical activity levels which have declined to a chronically low intensity. This age-related muscle atrophy appears to be the result of a reduction in the size of individual fibers and/or a loss of individual fibers (Larsson et al., 1978; Aniansson et al., 1983; Lexell et al., 1988) and is associated with great decreases in muscle strength and power especially at the onset of the sixth decade both in men and women (Frontera et al., 1991; Häkkinen and Häkkinen 1991; Häkkinen et al., 1995, 1996). It has also been reported that age-related decreases in maximal power production take place actually to a greater degree than that of maximal muscle strength (Bosco and Komi 1980; Häkkinen and Häkkinen, 1991; Häkkinen et al., 1995,1996). For example, Metter et

al., (1997) report that muscle power declines at a 10% faster rate than strength in aging men. Further, Skelton et al. (1994) have shown that isometric strength declines 1-2% per annum but muscle power approximately 3.5% per annum in men over 65 years old. To what extent these changes are related to the process of aging associated with alterations in hormone balance such as decreased androgen levels in both men and women (Häkkinen and Pakarinen, 1993) and/or to a decrease in the amount/intensity of normal daily physical activities is difficult to interpret.

Not only is maximal strength lower in the aged but the ability to develop force rapidly. In a study by Thelen et al. (1996b) the old adults tested required substantially more time to reach given torque magnitudes than the young adults did. For example, the young and old females needed approximately 236 and 337 ms to develop 15 Nm of dorsi flexion torque, of which 141 and 164 ms were reaction times. Isometric mRFD was 25% to 36% lower in the old than in the young adults. The age declines in isometric torque development time were associated with losses in maximum isometric strength. Maximum isokinetic torques developed by the old were 20 to 40% lower than those of young adults. Interestingly, the percent losses in isokinetic torques with age were independent of joint angular velocity for plantar flexion, but increased with velocity for dorsi flexion. The authors concluded that there are substantial age declines in abilities of healthy old adults to rapidly develop ankle joint torques and their capacity to recover balance or to carry out other time-critical actions, which require moderate-to-substantial strength and power, may be considerably degraded by these declines (Thelen et al., 1996b).

In a further study designed to investigate the cause of these declines Thelen et al. (1996a) neural activation was compared in young versus old people. Myoelectric signals were measured in 24 healthy young and 24 healthy old adult volunteers during rapid isometric and isokinetic torque development. Premotor times, muscle activation rates, and myoelectric activity levels of agonistic and antagonistic muscles were quantified. There were few marked age differences in the premotor times or in the onset rates or magnitudes of agonist muscle activities during maximum isometric and during isokinetic exertions. Premotor times were statistically associated with age but only a mean of approximately 10 to 25 ms longer in the old. Age effects on agonist muscle activity magnitudes were significant only in the lateral gastrocnemius. Small decreases in antagonistic muscle activity levels with age were also found (Thelen et al., 1996a). It was concluded that the differences observed previously in rapid torque development abilities in healthy older adults, compared with healthy younger adults (Thelen et al., 1996b), seem attributable largely to differences in muscle contraction mechanisms rather than to differences in speeds of stimulus sensing or central processing of motor commands, or to differences in muscle recruitment strategies (Thelen et al., 1996a).

Muscle atrophy would appear to be the primary cause of the muscle weakness and decline in muscle power with aging. This atrophy results from a gradual process of fiber denervation with loss of some fibers and atrophy of others (Faulkner and Brooks, 1995). Fast fibers show more denervation and atrophy than slow fibers. Some fast fibers are reinnervated by axonal sprouting from slow fibers resulting in remodeling of motor units (Kadhiresan et al., 1996; Kanda and Hashizume, 1989). With aging, the decreases in strength and power are greater than expected from the loss of muscle mass. Contraction-induced injury has been proposed as a mechanism of the fast fiber denervation (Brooks and Faulkner, 1994), however, Lexell (1997) has suggested the death of motor neurons as the more plausible mechanism responsible for the decline in muscle mass with aging.

A loss of muscle power has been shown to have profound effects on functional activities such as speed of walking up stairs, standing up from a chair and gait speed (Bassey et al., 1992). Given that recovering balance after a trip or slip, requires the application of a large amount of force in a short period of time, muscle power should be a significant factor in risk of falling (Evans & Campbell, 1993). This hypothesis is supported by previous research, which demonstrates a clear relationship between maximal muscle power and a static balance test (Bassey et al., 1992).

Falling is known to be one of the most serious problems facing older persons (Maki et al., 1990). The fractures, surgical procedures, hospitalisation, and complications, which often result from such falls, ensure that falling remains the leading cause of accidental death in the 65+ age group. In terms of incidence of falling, approximately one-third of all persons over the age of 65 fall at least once per year (Baker & Harvey, 1985).

Murphy and Isaacs (1982) surveyed 125 people aged 65 and over who fell in their own homes. Three fractured their femurs and 15 had other fractures; most of the rest suffered only trivial injuries. One-quarter of these patients died within one year of the fall, five times as many as in an age- and sex-matched control group. The social and financial implications are enormous. Perhaps even more significant than the acute injuries are the psychological after-effects of experiencing a fall: the so-called post-fall syndrome, a severe fear of falling, which limits mobility and independence (Murphy and Isaacs, 1982). Although falling is a complex and multi-factorial problem, the decline in muscular strength and power has been suggested as a significant factor (Evans & Campbell, 1993; Era 1988).

There is a need for further research into the effects of aging on maximal power production. Perhaps specific power training will be effective for slowing or even reversing the loss of fast twitch fiber area and number, which occurs currently in our older people. Maximal power training

may have a greater effect on functional capacity and the performance of daily activities than other more traditional methods such as heavy resistance exercise. The influence of training to increase muscular power on an elderly person's risk of falling is also an area of research, which might yield fruitful results.

## Conclusions and Implications from the Literature Review

Maximal power performance is a multi-faceted phenomenon requiring the consideration of a large number of training factors. Of particular importance is the current status of the individual with regard to muscular strength in both fast and slow muscle actions, rate of force development capability, stretch shorten cycle ability, and inter-muscular coordination and skill. The greatest improvements in maximal power production will be realised if a range of training methodologies is implemented which address each of these components. If, however, a component is already highly developed (e.g., strength at slow movement velocities) then greater attention to other components (e.g., plyometric training for SSC performance) will be more rewarding. Ballistic resistance training is highly specific to maximal power movements and develops many of the components of the neuromuscular system, which facilitate such actions. However, there is the problem of controlling the large impact forces, which can be experienced during the eccentric phase of these movements.

There are a number of implications from the literature review:

There is a need to develop a system, which can be used to test and train maximal power production. This system should permit subjects to perform movements in which they can maximise their power output in safety and include the ability to alter the load, which the subject is required to move.

The system should be capable of measuring the displacement of the load with time and the force being exerted in the direction of movement. Subsequently the kinematics and kinetics of the performance should be derived to better describe the subject's performance in maximal power movements. The validity and reliability of the developed measurement system should be determined.

A mechanism will be required which will limit or allow control of the eccentric loading imparted to the subject. The effect of this mechanism on the impact forces imparted to the subject should be assessed as well as the influence on the subsequent concentric movement.

For the development of maximal power, traditional resistance training has been shown to be less effective than movements in which there is an attempt to maximise the velocity of movement. This is particularly true for subjects who are already strength trained. Differences in terms of kinetics, kinematics and muscle activation of traditional versus ballistic resistance training movements need to be investigated to gain an understanding of why ballistic resistance training

produces superior results.

The relationship between force, velocity and power output has been studied in bundles of muscle fibers (Faulkner et al. 1986; Hill 1938), single joint movements (Kaneko et al. 1983; Moritani et al. 1987; Perrine and Edgerton 1978), and multi-joint movements such as vertical jump (Bosco and Komi 1979; Komi and Bosco 1978). The majority of prior research concurs that the force capability of muscle in concentric actions decreases with increasing velocity of shortening and maximal power output is produced at approximately 30% of maximum isometric force and approximately 30% of maximum shortening velocity (Edgerton et al. 1986; Faulkner et al. 1986; Hill 1938; Kaneko et al. 1983; Moritani et al. 1987). However, this relationship requires further investigation in terms of ballistic resistance training movements and in particular for the upper body.

Stretch shortening cycle movements in the lower body have undergone a considerable amount of scientific investigation (Bosco and Komi, 1979; Bosco et al., 1982), however, the influence of the stretch shortening cycle on upper body power production has received limited attention (Bober et al., 1980).

Although Wilson et al. (1993) have established that ballistic resistance training is effective for increasing maximal power performance in moderately strength trained subjects, the efficacy of this type of training for already highly trained elite jump athletes has not been tested.

When improvements in maximal power performance arise from a ballistic resistance training programme there is a need to determine what aspects of the neuromuscular system outlined above have changed and in what ways to bring about performance enhancement.

Aging has a profound effect on muscular strength and maximal power output. Further research is required into the changes occurring in the neuromuscular system as we get older as well as the adaptations, which can be elicited in young versus old humans as a result of resistance training.

# ***Chapter 3***

## **EXPERIMENT ONE**

---

### **THE EFFECT OF A BRAKING DEVICE IN REDUCING THE GROUND IMPACT FORCES INHERENT IN BALLISTIC RESISTANCE TRAINING**

#### **INTRODUCTION**

The performance of high intensity stretch shorten cycle movements, such as depth jumping, have become a popular form of training for many athletes. This training modality, commonly termed plyometrics, has been shown to be effective in enhancing muscular power by improving the stretch shorten cycle capability of the neuromuscular system (Bosco, et al., 1982; Hakkinen, et al., 1985; Schmidbleicher, et al., 1988). Wilson et al., (1993) have found large increases in power production to result from “ballistic” resistance training in which the subject jumps with or throws a load in a manner which maximises the power output.

A problem arises in maximal power training with regard to the high eccentric loads and impact forces placed on the musculoskeletal system. Several authors have identified this loading as a potential injury risk (Dufek and Bates, 1990; Nigg, et al., 1981; Scott and Winter, 1990). A thorough evaluation of impact forces during landing has been published by Dufek and Bates (1990) who investigated a number of parameters related to the resulting peak vertical ground reaction force (VGRF). It was found that peak VGRF increased with the height of jump such that distances of 0.40 m, 0.60 m and 1.00 m resulted in impact forces of 3.00, 3.44 and 4.77 times body weight (BW) respectively. These results are significant because for ballistic or plyometric training to be effective the athlete should aim towards maximum jump height and/or minimum ground contact time. Both

of these factors contribute to the production of high impact forces on landing. Any additional weight added to the landing athlete will also increase the impact force (Frederick, et al., 1981).

Typically, the performance of plyometric exercises requires the musculature and joint mechanisms involved in the landing process to dampen the impact forces placed on the body. On landing, there is a sharp rise in force immediately following the first ground contact (Devita & Skelly, 1992; Nigg, Denoth & Neukomm, 1981). This rapid initial sharp peak in the ground impact force has possible implications for injuries to the lower limbs related to landings (Munro, Miller & Fuglevand, 1987; Ricard & Veatch, 1990). A number of investigations have quantified the initial impact by calculating the impulse which occurs within the first 50 ms of landing (Bosco, Mogroni & Luhtanen, 1983; Ricard & Veatch, 1990) and speculated that this *impact impulse* may result in injuries to the muscular and skeletal systems (Ricard & Veatch, 1990).

The impact forces, which the body sustains from landing, appear to be influenced by the inter-relationship between several mechanical parameters. The height of the jump (Dufek & Bates, 1990; Stacoff, Kaelin & Stuessi, 1988) and the loading applied to the body (Frederick & Hagy, 1986; Gollhofer & Kyrolainen, 1991; Scott & Winter, 1990) can be directly related to the velocity at impact (Devita & Skelly, 1992; McNitt-Gray, 1991; Munro, Miller & Fuglevand, 1987; Valiant & Cavanagh, 1983). Subsequently it is the momentum attained prior to ground contact, which influences the impact loads upon landing (McNitt-Gray, 1991). Landing technique (Frederick & Hagy, 1986; Scott & Winter, 1990; Steele, 1989), has also been shown to effect the impact forces and it has been documented that stiff legged landings produce higher impact forces than landings which attempt to dampen the movement with hip and knee flexion (Devita & Skelly, 1992; McNitt-Gray, 1991; Zatsiorsky & Prilutsky, 1987).

A general conclusion of several authors (Dufek and Bates, 1990; Nigg, et al., 1981; Steele and Milburn, 1987; Valiant and Cavanagh, 1983) has been that any method which could reduce the high VGRF during impact requires further investigation. Recognising the problem of high impact forces during ballistic resistance training, a braking system was developed to reduce the loads applied to the subject during the downwards phase of the movement.

The purpose of this study was to investigate the effect of this braking mechanism on the impact forces associated with high intensity ballistic resistance training. Additionally, the effect of reducing the eccentric load on the subsequent concentric force production and performance was also assessed.

# METHODS

## **Subjects**

Seven male and thirteen female subjects volunteered to participate in this study. All subjects were recruited from the university population and were currently involved in a range of sports and activities (basketball, netball, football, athletics, and aerobics) which required powerful leg movements. The mean subject characteristics for age, height and mass are summarised in Table 3.1.

The study was approved by the Human Ethics Committee of the University of New England, Northern Rivers. Prior to the commencement of the study all subjects were verbally informed about the experimental procedures before signing an informed consent document (Appendix C).

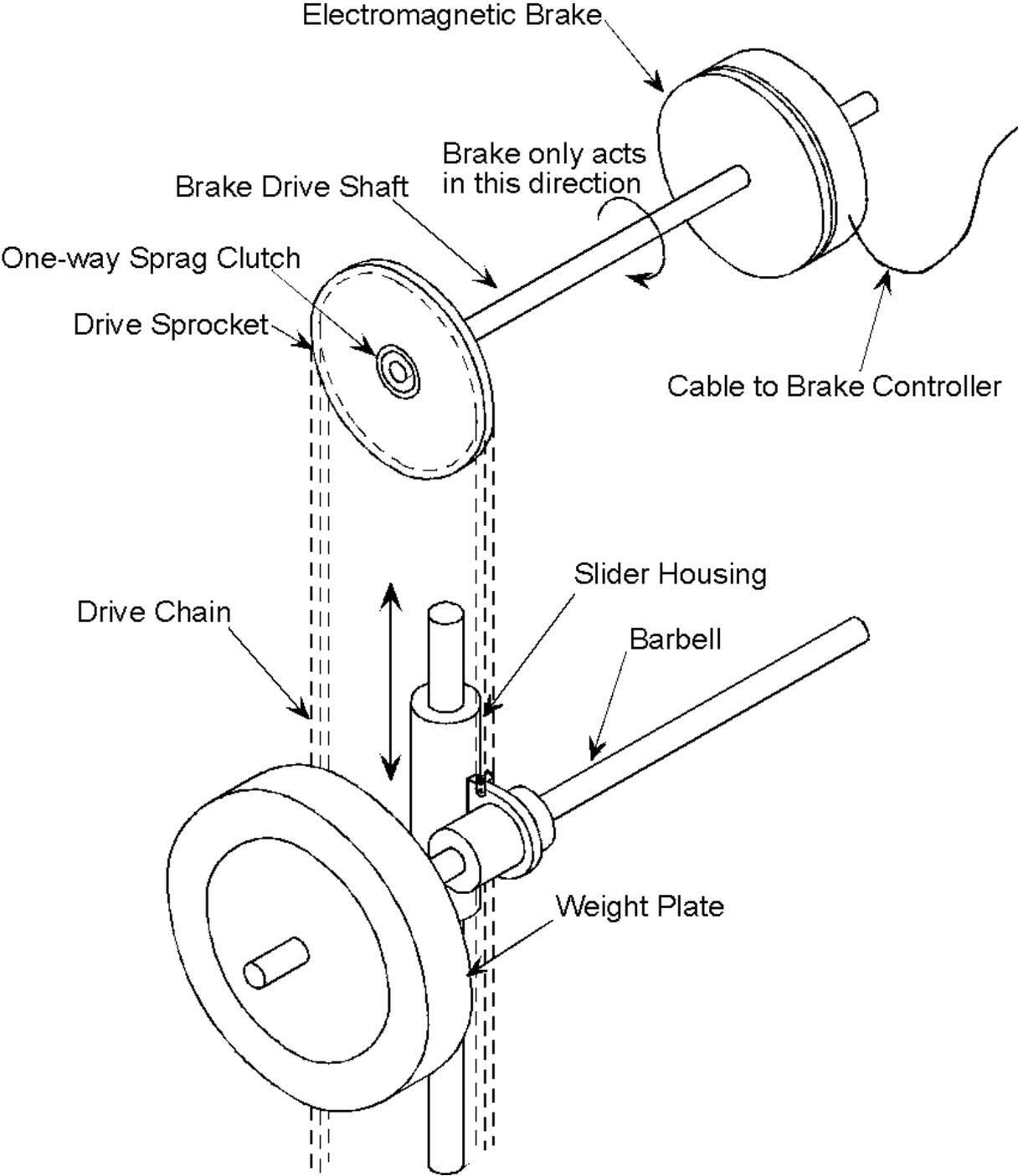
**Table 3.1** Subject characteristics

	Age (yrs)	Height (cm)	Mass (kg)
Male (n=7)	19.7 ± 2.1	179.0 ± 7.3	69.3 ± 11.2
Female (n=13)	21.8 ± 5.6	166.8 ± 8.4	61.4 ± 7.7
Total (n=20)	21.0 ± 4.7	171.1 ± 9.8	64.2 ± 9.6

## **Equipment**

The Plyometric Power System (PPS)(Norsearch, Lismore, Australia) enables subjects to perform ballistic resistance training exercises with a loaded bar which is housed in a heavy metal frame that limits movement to a purely vertical plane (Figure 4.1). The machine limits bar movement to the vertical plane and the downward movement of the bar can be controlled within an accuracy of 0.02 m. The movement of the bar is achieved by the use of linear bearings attached to either end of the bar. This allows the bar to slide up and down two hardened steel shafts with a minimum of friction. The machine is connected to a rotary encoder measurement system (Chapter Three) which produces pulses indicating the displacement of the bar. One pulse was produced for each 0.00106 m of bar movement. Each pulse was recorded by a counter timer board installed in a 386DX IBM compatible computer which was capable of measuring pulse frequencies up to 1MHz. This information was recorded by computer and software calculated the work done (mass x gravity x height) and mean power output (work/time). The system was calibrated prior to use by measuring the total number of pulses produced as the bar was moved through its full vertical range (2.8 m).

The braking system incorporates an electro-magnetic clutch (Warner Corporation, IL) which can be adjusted by varying the current supplied to produce a static frictional force of 0 to approximately 1500N. The braking action only engages during the downwards movement of the bar due to the action of one-way sprag clutches installed in the sprockets attached to each end of the shaft passing through the clutch mechanism (Figure 3.1).



**Figure 3.1** The electromagnetic brake on the Plyometric Power System.

**Experimental design and testing**

Prior to testing a standard warm-up involving a 5 minute cycle at 60 rpm at a workload of 60 W was performed on a Monark stationary bicycle. On completion of the cycle subjects were

instructed to perform a 3 minute standard stretching routine for the lower body. Prior to data collection subjects familiarised themselves with the testing equipment by performing a series of submaximal jumps with and without the braking mechanism engaged.

On each test subjects performed four successive jumps while being instructed and encouraged to jump for maximal height. Using a repeated measures design the sequence of presentation of both jump conditions was randomised to control for order effects among subjects. The first group initially performed the jumps with the brake mechanism engaged, followed by jumps without the braking system engaged. The second group were tested in the reverse order to that of the first group. Between all repeat jumps a 3 to 5 minute recovery period was imposed to negate any physiological effects of fatigue (Wilson et al., 1993)

### **Braked Jumps**

The braked jump condition, which reduced the landing velocity of the eccentric phase of the movement, was performed on the PPS and will be termed a 'braked jump'. The PPS enables standard weight training exercises to be performed in a ballistic manner (Wilson et al. 1993) and has the capacity to control eccentric loading through the electronic braking mechanism previously described. The braked jumps were performed on the PPS with the braking system set to a static frictional force equivalent to 75% of the individuals body weight, including the 10 kg (98.1 N) bar weight.

During each jump, once the subject attained their maximal jump height and commenced in a downward direction, the sprag clutches engaged and braking was applied and maintained throughout the descent of the jump. Because the heaviest subject tested was only 86 kg (843.7 N) the maximum braking force required was 75% of the combined body weight and 10 kg bar (98.1 N). Therefore, the braking level which was needed for this individual was  $(843.7 + 98.1) \times 75 / 100 = 706.4$  N, which is well within the upper limit of the brake. A 75% braking force was selected from pilot data as it represented a level which appeared to reduce the downward momentum of the subject prior to landing without negating the stretch shorten cycle nature of the jump.

All jumps performed on the PPS used a 10 kg bar secured to the shoulders by a harness fastened to the upper torso and the subjects performed the jumps with a minimum knee angle of 110 degrees which was visually monitored (Bosco, Luhtanen & Komi, 1983; Bosco, Mognoni & Luhtanen, 1983). Beyond this depth the knee angle was restricted as the safety mechanisms on the PPS were positioned to restrict excessive knee flexion (Figure 4.1).

## **Non-Braked Jumps**

The jump condition involved jump squats performed while holding a 10 kg barbell across the shoulders. These jumps are termed 'non-braked jumps' as they were not performed using the braking system. The non-braked jumps were administered without the PPS and its braking mechanism to simulate plyometric training as performed in most traditional plyometric training routines. The non-braked jumps were standardised by ensuring that the same knee flexion angle of 110 degrees was adhered to while jumping. The depth was visually monitored (Bosco, Luhtanen & Komi, 1983; Bosco, Mognoni & Luhtanen, 1983) and any subject who flexed the thigh beyond this level was retested.

## **Force Measurement**

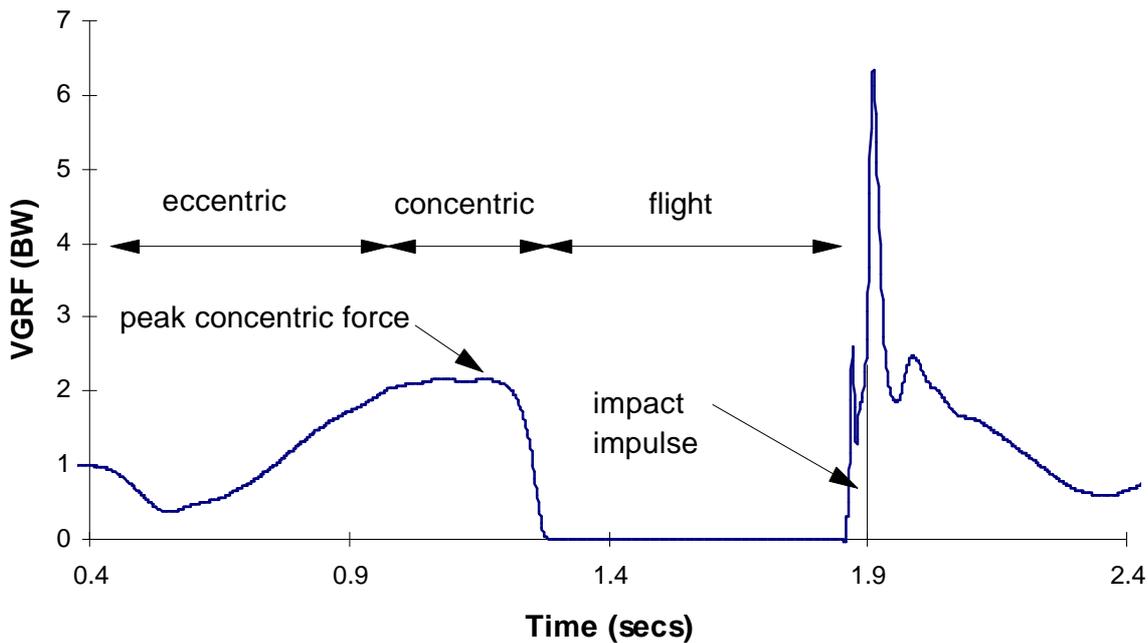
Vertical ground reaction forces were measured using a forceplate (Kistler, Type 9287, Switzerland) which was mounted flush with the floor. During the braked jump condition the PPS was secured over the forceplate so that each subject landed centrally on the forceplate. Prior to the collection of all data the forceplate was reset to zero. The force data output was recorded via a charge amplifier to a 14 bit analog to digital converter board in an IBM AT compatible computer. All data was recorded at a rate of 550 Hz, over a 5.5 s period, and stored to disk for later analysis. The forceplate was calibrated immediately before and after the testing session.

For both the braked and non-braked jump conditions the vertical ground reaction forces were normalised to the subject's body weight. The force data for each of the two conditions were then used to calculate the following impact parameters (Figure 3.2): peak impact force, impact impulse and peak concentric force production. The impact impulse was defined as the area under the vertical ground reaction force curve during the first 50 ms of the impact phase (Ricard & Veatch, 1990). All data were averaged for the second and third jumps performed in the four jump series.

## **Statistical Analysis**

The data for the braked and non-braked jumps were statistically compared using a two-way analysis of variance (ANOVA) (gender x 2 conditions) with repeated measures on one factor (condition). There was no significant ( $p \leq 0.05$ ) difference between the results for the male and female subjects. Subsequently the data were pooled together into braked and non-braked groups. A two-tailed paired t-test using an alpha level adjusted for multiple comparisons using the Bonferroni technique was then applied to identify differences between the braked and non-braked jump conditions. A criterion alpha level for statistical significance of  $p \leq 0.05$  was used with a corrected

alpha of  $p \leq 0.017$  for the three comparisons.



**Figure 3.2** A representative vertical ground reaction force curve. The following parameters are shown: peak concentric force, impact impulse, flight time, the concentric phase and the eccentric phase of the jump. Impact impulse - was calculated as the area (sum of force x time) under the vertical force curve during the first 50 ms of the impact phase.

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## DELIMITATIONS

1. The samples chosen for this study were limited to adult males and females who were physically active though not athletes.
2. The determination of impact characteristics was limited to the jump squat.

## LIMITATIONS

In addition to limitations arising from the above:

1. The amount of braking force applied could only be estimated for the static frictional force and dynamic braking was not determined.

## RESULTS

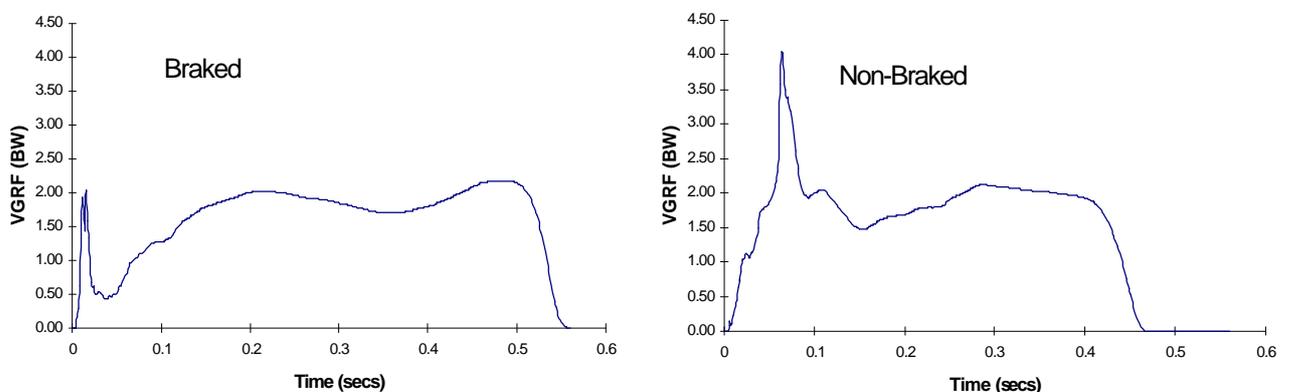
A comparison between the braked and non-braked jump conditions are summarised in Table 3.2. The mean peak vertical ground impact force for the braked vertical jump was 61% lower ( $p \leq 0.05$ ) than the impact experienced by the non-braked vertical jump condition.

**Table 3.2** Comparison between 'Braked' and 'Non-Braked' jump conditions.

	'Braked' Jumps	'Non-Braked' Jumps
Peak impact force (BW)	1.19 ± 0.26	3.04 ± 0.49*
Impact impulse (BW.sec)	0.30 ± 0.17	0.90 ± 0.26*
Concentric Force (BW)	2.32 ± 0.30	2.19 ± 0.34

\* Statistically significant difference between 'Braked' and 'Non-Braked' jump conditions,  $p \leq 0.05$ .

The impact impulse was 67% lower ( $p \leq 0.05$ ) in the braked jump condition than in the non-braked jump condition. There was no significant ( $p \leq 0.05$ ) difference between the peak concentric force production for the braked jump and the non-braked jump.



**Figure 3.3** A representative subject's vertical ground reaction force during a landing and subsequent jump. Examples for the 'braked' and 'non-braked' jump conditions are shown.

## DISCUSSION

The purpose of this study was to investigate the effects of a braking mechanism on the ground impact forces associated with ballistic resistance and plyometric training. The peak impact forces obtained for the braked and non-braked jump conditions represents a 61% reduction in impact force for the braked jump condition. The corresponding VGRF for the two jump conditions are presented for a representative subject in Figure 3.3. The peak impact force of the non-braked jump condition of 3.04 BW are similar to those reported in the literature for jumps (Dufek & Bates, 1990; McNitt-Gray, 1991; Steele, 1989; Valiant & Cavanagh, 1983). However, the peak impact force obtained for the braked jumps of 1.19 BW, was much lower than those reported for landings (Devita & Skelly, 1992; Dufek & Bates, 1990). The lower ground impact forces resulting from the use of the braking mechanism has the potential for reducing the incidence of injury.

## **Impulse**

The impact impulse was significantly different between the two jump conditions such that the braked jump condition represents a 67% reduction in the impact impulse occurring in the first 50 ms of ground contact. These findings are relevant to landings in that high impulses which occur within 50 ms of impact are associated with the potential for injury (Munro, Miller & Fuglevand, 1987; Nigg, Denoth & Neukomm, 1981; Ricard & Veatch, 1990). The jumps performed with the braking device enabled the impact impulse to be significantly lowered, thus reducing the risk of injury (Dufek & Bates, 1990; Munro, Miller & Fuglevand, 1987; Nigg, Denoth & Neukomm, 1981; Ricard & Veatch, 1990; Scott & Winter, 1990).

By successfully reducing the peak impact force and impact impulse at landings the risk of injury to soft tissue and skeletal mechanisms can be alleviated. The braking mechanism may therefore have implications for rehabilitation and athletic training. The arduous process of rehabilitation often requires a gradual transition from static, dynamic and then specific muscular actions. However, the rehabilitation process may be expedited by the performance of loaded SSC actions whereby the load can be specified and velocity at impact modified. This would benefit the rehabilitation process by directly focusing movements at the specific nature of the injury and intended sports performance.

## **Concentric Force Production**

The results of concentric force production would suggest that there was no adverse effect on the concentric performance of the braked jump stemming from the application of the brake. As a consequence of performing ballistic SSC exercises the musculature utilises the elastic strain energy and the neuromuscular patterns within the system which serve to facilitate performance (Schmidtbleicher, Gollhofer & Frick, 1988). The reduction of the eccentric load with the braking mechanism could alter the elastic transfer between the prestretch and shortening phase thus changing the intended training response. However, the results of this study demonstrate that the application of the brake results in no adverse effects on concentric force production. Although mere speculation, this may further support the notion that elastic energy only plays a minor role in enhancing subsequent concentric performance and it is the pre-load which is the more significant factor (Bobbert et al., 1996).

Any landing strategy that will allow the performance of ballistic and plyometric type exercises, such as depth jumps and weighted jump squats, with increasing heights and loads while reducing the velocity of impact has the potential to modify the training effect. The PPS has applications to athletic training whereby the braking device can allow the safe performance of

heavily loaded ballistic resistance training exercises, such as jump squats, with loads in excess to that which are possible without a braking mechanism.

The use of a braking system to control the velocity prior to landing has implications to the performance of exercises such that the SSC movement can be negated in full, in part or not at all. As such the braking mechanism has the capacity to influence the performance of ballistic resistance exercises in both athletic training and the rehabilitation environment. With no braking applied an athlete can perform a variety of exercises of a ballistic nature to develop maximum muscular power. When the braking force is applied in a progressive manner, to the athlete or during rehabilitation, one can selectively develop concentric force production using heavy weights to perform exercises, such as jump squats, while limiting impact forces upon landing. Alternatively, during the rehabilitative process, or, athletic training, one can graduate the adaptation to high eccentric forces inherent in ballistic resistance training exercises by reducing the amount of braking.

## **CONCLUSIONS**

The use of the electronic braking device on the PPS has been shown to be effective in reducing vertical ground impact force (61%) and the impact impulse at landings (67%). These results may indicate that by successfully reducing these impact parameters the likelihood of sustaining an injury from excessive impact forces has been decreased. Furthermore, the braking mechanism did not interfere with the ballistic concentric nature of the jumping action. The use of the braking device not only has the potential to reduce injury it can also be used in rehabilitation of athletes where ballistic closed kinetic chain movements, such as jump squats, can be performed without large impact forces. Further research work is required to assess the efficiency of such a device in rehabilitation and the effect of reducing the eccentric load on maximal power development.

# ***Chapter 4***

## **EXPERIMENT TWO**

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### **A COMPARISON OF THE TRADITIONAL AND BALLISTIC RESISTANCE TRAINING MOVEMENTS**

#### **INTRODUCTION**

Sporting activities involving striking, throwing, jumping or rapid acceleration movements require a high power output of the involved muscles rather than high force production. Subsequently, athletes and coaches have modified training program design in an attempt to develop maximal power rather than primarily maximal muscle strength. These modifications recognize the findings of the exercise science research that heavy resistance training with slow contraction velocities does not effectively increase muscular power particularly in already strength trained subjects (Häkkinen & Komi, 1985a; Kaneko et al., 1983; Wilson et al., 1993).

One strategy used by many strength coaches has been to simply instruct their athletes to move the resistance as rapidly as possible, often using a lighter relative load. However, the rationale for developing maximal power by performing traditional resistance training barbell and machine exercises in a rapid manner could also be questioned (Wilson et al., 1993). This is because during conventional resistance training exercises, a substantial portion of the lift involves a period when the bar is decelerated prior to achieving zero velocity at the end of the concentric movement (Elliott et al., 1989; Wilson et al., 1989). The deceleration phase is evident during maximal lifts and has been found to increase to 51.7% of the concentric movement when lifting a submaximal load of 81% of maximum bench press load (Elliott et al., 1989). Further, the deceleration phase was accompanied by a reduction in EMG activity of the agonists in the movement (Elliott et al., 1989).

A conclusion of Wilson et al. (1989) was that the movement pattern during an 81% of maximum load lift was not specific to that adopted during a maximal lift and that training with a submaximal load may not result in the highest gains in maximal lift performance.

When attempting to increase maximal power by performing rapid traditional weight training movements with a light load, it is reasonable to expect that this deceleration phase would also be evident. However, the kinematics and kinetics of such movement have not been examined, and to our knowledge, no research has been conducted into a common exercise such as the bench press performed powerfully using light loads.

The purposes of this study were to 1) investigate the kinematics, kinetics and muscle activation when an athlete attempts to perform a traditional bench press in a powerful manner; and 2) compare the kinematics, kinetics and muscle activation during a bench press with that of a bench throw in which the athlete actually releases the load at the end of the motion in a ballistic manner. It was hypothesized that the bench throw would be superior in terms of velocity, force, power output, and muscle activation compared with the bench press. Should this be true, such ballistic movements may represent a superior form of resistance training for the development of maximal power.

## **METHODS**

### ***Subjects***

Seventeen healthy males volunteered to take part in the study. The subjects were not athletes but were recreationally weight training and none of the subjects had reported use of any anabolic drugs. All subjects had been weight training for a minimum of six months and could bench press at least their own body weight. The subject's mean ( $\pm$ SD) age, height and weight were  $20.6\pm 1.9$  yr,  $1.79\pm 0.06$  m and  $83.7\pm 8.2$  kg respectively. The study was approved by the Ethics Committee of the Southern Cross University, and all subjects signed an informed consent document prior to the commencement of testing (Appendix D).

### ***Testing Procedures***

Testing was conducted over two sessions separated by four days. During the first testing session the subject's one repetition maximum (1RM) load for the bench press was determined according to the procedures of Young and Bilby (1993) using a Plyometric Power System (PPS)(Figure 4.1)(Wilson et al, 1993). The subject's age, weight, and height were also recorded during this session. The subject then completed a number of bench throws using a load of 45% of

1RM to become familiar with the test movement. Each subject was instructed to begin with the weighted barbell held at arms length, then lower the bar to the chest and immediately push it upwards attempting to project the bar for maximal height. The height of each throw was recorded and the subject was required to repeat the movement until no further increases in throw height were produced. The subjects had not performed bench throws previously and as such, these throws served as familiarisation for the second testing session.

The second test session began with a general warmup involving two sets of 10 bench presses at a submaximal load of 45% of 1RM followed by 5 minutes of chest and triceps brachii static stretches. The subject was then instructed to lie on the bench of the PPS such that the bar crossed the chest at the level of the nipples. To allow for comparison of EMG recorded during later trials, the subject completed a single bench press with a load equal to his previously determined 1RM. All subjects could complete the 1RM trial. Two movements were then tested each using a load of 45% of the subject's previously determined 1RM: 1. A bench press was performed for which the subject was instructed to lower the bar to the chest, "accelerate off the chest" as rapidly as possible and then stop the bar at arms length. The subject supported the bar in the hands at the completion of the typical bench press movement. 2. A bench throw for which the subject was instructed to lower the bar to the chest then "accelerate off the chest" as rapidly as possible, attempting to throw the bar for maximum height. During ballistic movements (e.g. throw or jump) mechanical power is maximised at a load of 30% 1RM (Kaneko et al., 1983), however, during more traditional lifts (e.g. bench press or squat) Hatfield (1989, pge 133) suggests that power is maximised at loads of 55% or higher (Hatfield, 1989). Thus, 45% of 1RM was chosen as a load which would allow comparison of the two movements studied. Prior to each trial the forceplate was zeroed with the subject in position to remove the weight force of the subject and bench from the vertical ground reaction force measurement.

The braking mechanism on the PPS as described in Chapter Four stopped the bar at the top of its flight so that the subject did not catch the bar after the throw. In both conditions the subject was not permitted to raise the shoulders or trunk off the bench. If this occurred, the trial was rejected and was subsequently repeated. No pause was allowed between the eccentric and concentric phases and the trial was rejected if the subject "bounced" the bar off the chest. Three trials were completed for each condition with 3 minutes rest between each trial. The order of the conditions was randomized between subjects to reduce the possible confounding effects of fatigue or boredom. During each press and throw trial, bar displacement data from the PPS, vertical force from a force plate, and EMG data were collected and stored for later analysis.

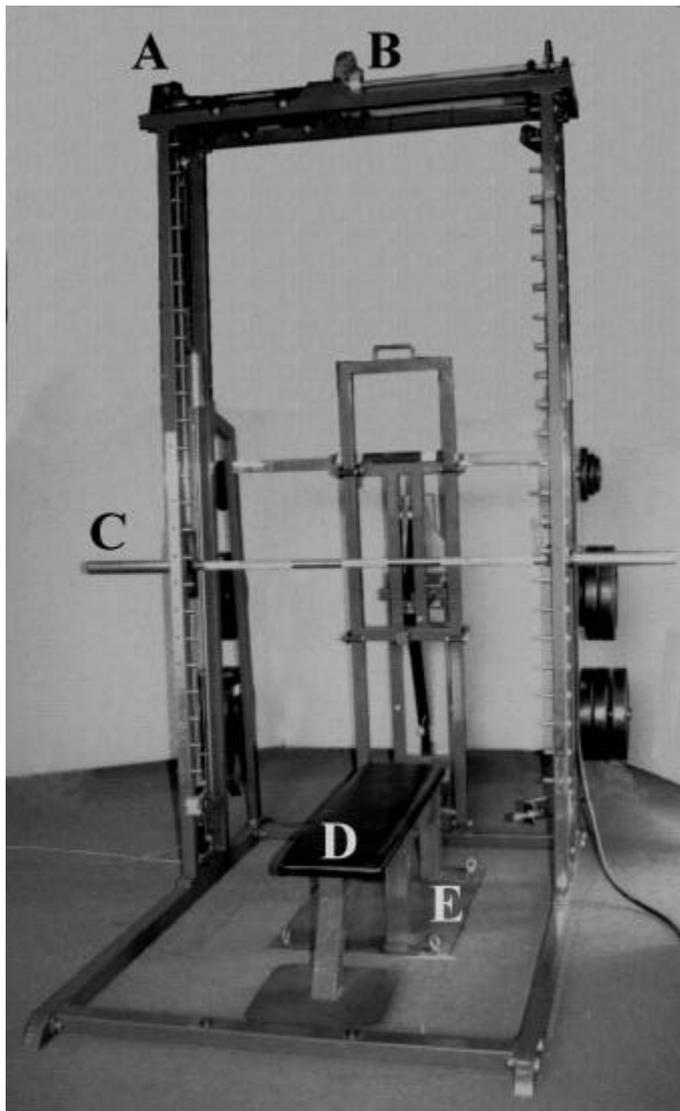
## **Equipment**

### **Plyometric Power System**

The Plyometric Power System (PPS) (Figure 4.1) (Norsearch Limited, Lismore, Australia) allows traditional barbell weight training movements such as bench press and squat to be done in a dynamic, ballistic manner and has been described elsewhere (Wilson, et al., 1993). A rotary encoder (Omron Corporation, Japan) attached to the PPS and interfaced with the computer, enabled the bar position to be measured with an accuracy of 0.001 m (*see* Appendix A). The system was calibrated prior to each testing session by counting the total number of pulses produced as the bar was moved through its full vertical range of 2.8 m.

### **Force Measurement System.**

Vertical ground reaction force was measured by means of a bench conforming to International Powerlifting Guidelines which was isolated on a Kistler force platform (Type 9287) and attached by four bolts. The amplified signals from the charge amplifiers were passed to a CIO-DAS16 analog to digital card (Computer Boards, Mansfield, MA) in a 80386DX computer running MSDOS. The digitized data were stored on computer disk for later analysis. The force measurement system was calibrated prior to each testing session.



**Figure 4.1** Plyometric Power System, bench, and force plate: The rotary encoder (A) measured bar position and the electromagnetic brake (B) controlled downward bar movement. The resistance of 45% 1RM was produced by the addition of weight plates to the bar (C). The subject lay on the bench (D) which was isolated on the forceplate (E) allowing measurement of vertical force output.

## Electromyography

During all throws each subject had four silver/silver chloride surface electrode modules (Quantec, Brisbane, Australia) attached over the belly of the long head of triceps brachii, the anterior deltoid, the sternal portion of the pectoralis major, and the biceps brachii muscle. Each electrode module consisted of two active electrodes and a third reference electrode all equi-distant at 2 cm. The active electrodes were aligned in parallel with the direction of pull of the muscle under investigation. Before electrode application, each site was shaved, cleansed with alcohol, gently abraded and a small amount of conductive gel applied to each electrode. The impedance between each electrode pair was then measured to ensure resistance was below 5 kOhms. Preamplifiers (Quantec, Brisbane, Australia) were incorporated into the electrode modules with the signal being further amplified using amplifiers (Quantec, Brisbane, Australia) with a low pass filter setting of

1 kHz and a high pass filter at 3 Hz. The amplified myoelectric signals were collected using an 80386DX computer running MSDOS and a CIO-DAS16 analog to digital card (Computer Boards, Mansfield, MA). The digitized data were stored on computer disk for later analysis.

Bar displacement, vertical ground reaction force and EMG data were sampled simultaneously, each at a frequency of 876 Hz.

## Data Analysis

Of the three trials recorded for each condition, the trial which resulted in the highest mean

power output was chosen for further analysis. The displacement time data was filtered using a fourth order Butterworth digital filter with the optimal cut-off frequency (14 Hz) determined using the Jackson “knee” method (Jackson, 1979). The concentric phase was determined as the time from when the bar velocity changed from positive to negative (bottom of movement) to the time at which the bar reached or passed the position it was in at the start of the eccentric phase. Average velocity, peak velocity and average force were determined for the concentric phase of each trial. Peak force was determined as the highest force during the entire eccentric and concentric movement. Instantaneous power output was calculated as the vertical force multiplied by the bar velocity ( $P = F \times v$ ). The average power output was calculated as the average of the instantaneous power measured through the concentric phase. Peak power was the highest power output measured during the concentric phase.

EMG data was quantified in two ways. 1) The average EMG was calculated by full wave rectification followed by mathematical integration (Simpson Method) with respect to time over the concentric phase, then divided by the time of the concentric phase. This value was then normalized by expressing it relative to the average EMG recorded during the concentric phase of the 1RM trial. 2) Peak EMG was calculated by integrating the rectified EMG over consecutive 50 ms time periods and determining the highest activity level. These values were then normalized relative to the peak EMG activity during the 100% 1RM trial.

To further assess differences between the press and throw movements, the time and bar position when the peak velocity, peak force, and peak EMG occurred was also determined. The time was expressed relative to the start of the concentric phase with negative values indicating that the peak occurred during the eccentric phase. The position was expressed as a percentage of the total concentric bar movement relative to the bar position at the start of the concentric phase.

To determine if the press differed from the throw in terms of the eccentric movement, the peak velocity during the eccentric movement as well as the time and position relative to the start of the concentric movement were determined.

In order to compare the variables over the course of the concentric movement for the press versus the throw, each trial was divided into 11 points, one every 10% of the total displacement during the concentric movement. The velocity, force and EMG activity was measured at each of these positions. In the case of the muscle activity, the rectified EMG was then integrated over 25 ms above and below each point (i.e. 50 ms). This value was then expressed relative to the level of EMG recorded at the same bar position during the 1RM trial.

## **Statistical Analysis**

The results for mean velocity, peak velocity, mean force, peak force, mean power, peak power, mean EMG, peak EMG and the time and position of the peaks were compared using discriminant analysis with paired t-tests for follow-up comparisons and the method of Bonferroni used to correct for experiment-wise error rate (Thomas and Nelson, 1990). The velocity, force and EMG activity at each point during the concentric phase were compared both within and between movement types with repeated measures multivariate analysis of variance (MANOVA) using a full factorial model and a polynomial contrast method. This analysis was followed by Newman-Keuls post hoc comparisons to determine at which points the variables were significantly different between the conditions. The criterion level for significance was set at  $p \leq 0.05$ .

## **DELIMITATIONS**

The samples chosen for this study were limited to adult males who were experienced weight lifters.

The analysis of kinetics, kinematics, and muscle activation was limited to the bench press and bench throw movements.

Only four muscle groups on the right side of the body were analysed using myoelectric techniques (pectoralis major, triceps brachii, anterior deltoid, and biceps brachii).

Only the 45% 1RM load was used for the comparison of the traditional and ballistic movements.

## **LIMITATIONS**

In addition to limitations arising from the above:

Surface myoelectric techniques were used to estimate underlying muscle function particularly gross muscle action through iEMG. Increases in iEMG cannot be specifically attributed to increases in recruitment and/or rate coding or perhaps some other factors (e.g. temperature) with certainty, particularly the relative contributions of each mechanism.

Force output was measured through the bench rather than directly as the force exerted by the hands on the bar.

The surface EMG of the biceps brachii during a maximal contraction of this muscle was not determined.

The maximum sampling frequency that could be achieved with the data collection system used was 876 Hz.

## RESULTS

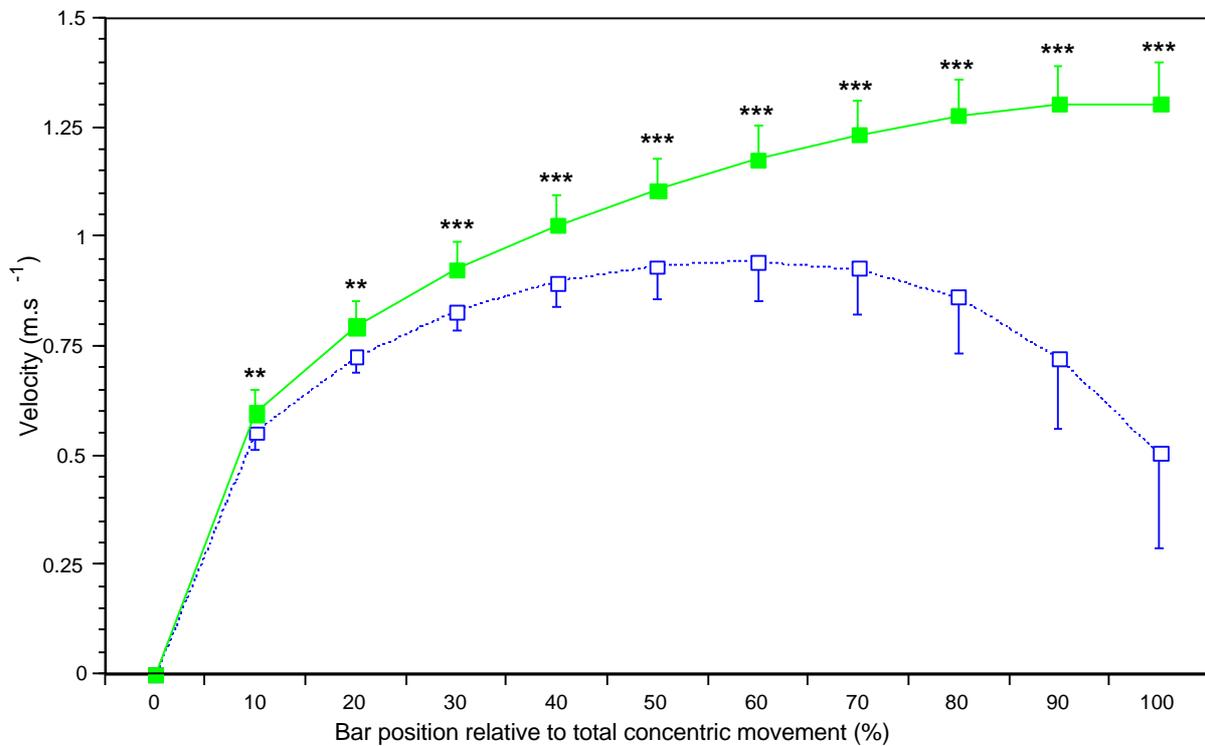
Several significant differences between the throw and the press were observed for the kinetic and kinematic variables (Table 4.1). Although the eccentric phases were similar, the concentric movement for the throw occurred over a shorter time period, with higher peak and average velocities. The peak in velocity occurred later in the movement for the throw indicating that the bar was being accelerated over a significantly greater portion of the concentric phase. The average force, average power, and peak power were all higher for the throw compared with the press.

There were significant differences between the press and the throw in the velocity (Figure 4.2) and force (Figure 4.3) profiles through the concentric movement. Further analysis revealed that the velocity was significantly higher during the throw movement after 10% of the bar movement and remained significantly higher at all subsequent positions analysed (Figure 4.2). Similarly, force at all bar positions analysed was significantly higher from the 10% position onwards (Figure 4.3).

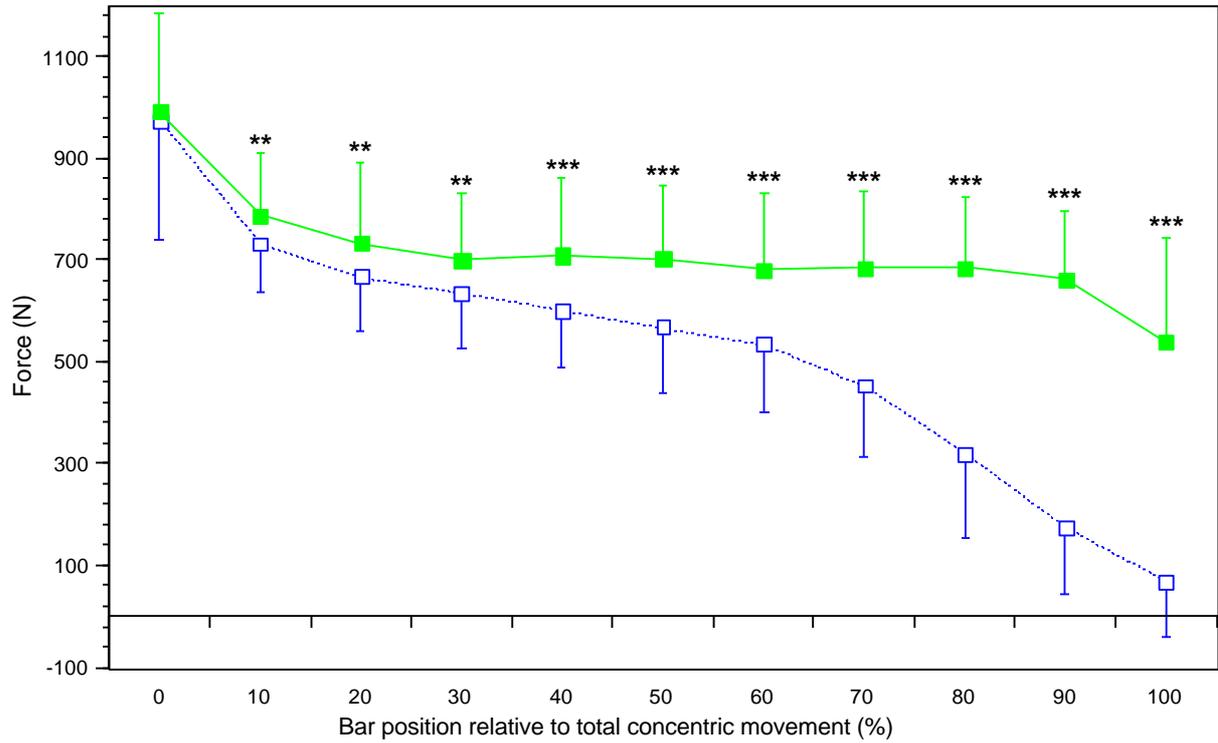
Average EMG was significantly higher for the throw for all muscles (Table 4.2), however, only the triceps muscle had a significantly higher peak EMG for the throw compared with the press (Table 4.2). Analysis of the EMG activity of the muscles through the concentric movement (Figures 4.4, 4.5, and 4.6) revealed the activity during the throw to be higher at several points with greater differences being evident during the later phases. Anterior deltoid (Figure 4.4) and triceps brachii (Figure 4.5) exhibited higher activation throughout the concentric phase. Pectoralis major activity was not different between the throw and press during the initial 50%-60% of the concentric movement but did show significantly higher activation for the throw at the end of the movement. Biceps brachii activity was not different between the throw and press during the initial 30% of the concentric movement but did show significantly higher activation for the remainder of the movement.

**Table 4.1** Summary data of time, velocity, force and power variables for the press and throw conditions with 45% of 1RM load (E.S. indicates effect size).

Variable	Press		Throw		Diff.	E.S.	P
	Mean	SD	Mean	SD			
Peak eccentric velocity ( $\text{m}\cdot\text{s}^{-1}$ )	-0.7	0.16	-0.77	0.22	10	0.188	0.078
Position (% eccentric displacement)	-48	6	-53	10	11	0.174	0.079
Time (ms from start of concentric)	-450	160	-360	150	-20	0.253	0.036
Peak force output during total movement (N)	1023	232	1050	202	3	0.034	0.549
Position (% concentric displacement)	0.03	1.9	0.63	1.4	2000	0.102	0.214
Time (ms from start of concentric)	10	30	10	30	0	0.056	0.232
Time of concentric movement (ms)	590	80	440	50	-25	0.754	<0.001
Average concentric velocity ( $\text{m}\cdot\text{s}^{-1}$ )	0.66	0.07	0.84	0.06	27	0.724	<0.001
Peak concentric velocity ( $\text{m}\cdot\text{s}^{-1}$ )	0.96	0.08	1.31	0.1	36	0.854	<0.001
Position (% concentric displacement)	60	10	96	8	60	0.866	<0.001
Time (ms from start of concentric)	370	60	430	50	16	0.479	0.003
Average concentric force (N)	559	124	757	125	35	0.892	<0.001
Average power output (W)	350	97	595	80	70	0.916	<0.001
Peak power output (W)	568	133	950	174	67	0.798	<0.001



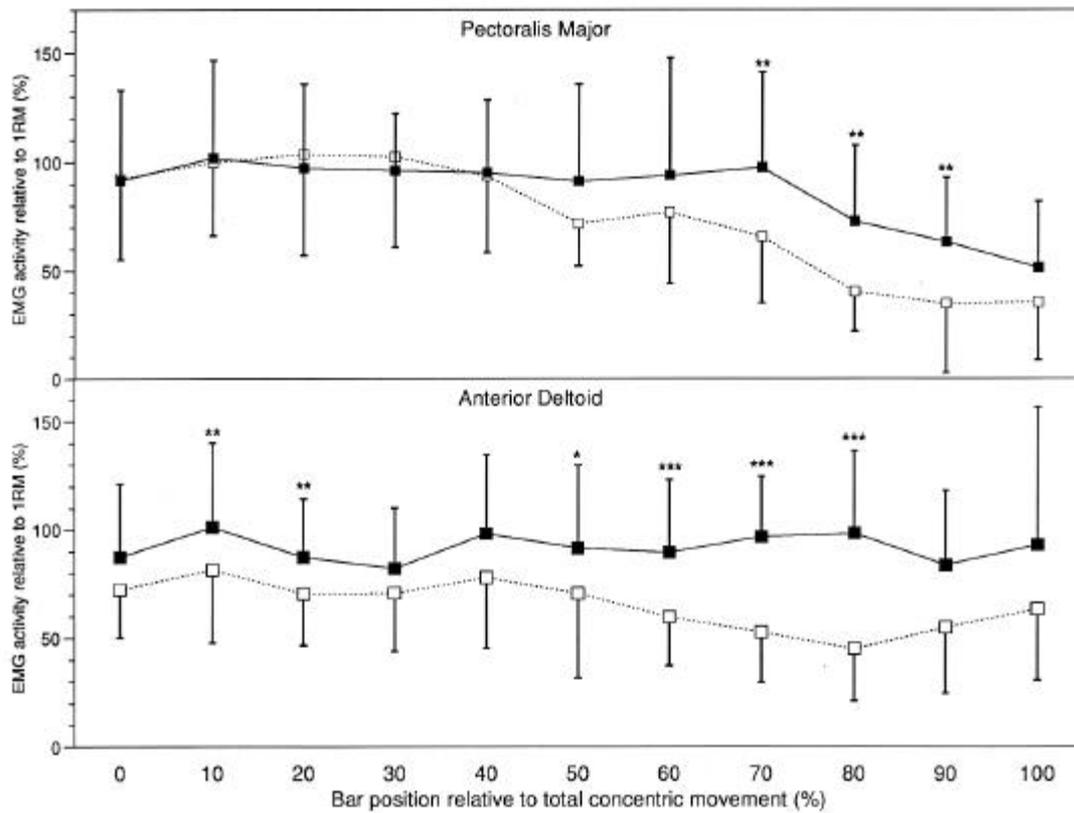
**Figure 4.2** Mean ( $\pm$ SD) bar velocity in relation to total concentric bar movement for the press (■) and throw (■) conditions (\*\* $p$ <0.01; \*\*\* $p$ <0.001).



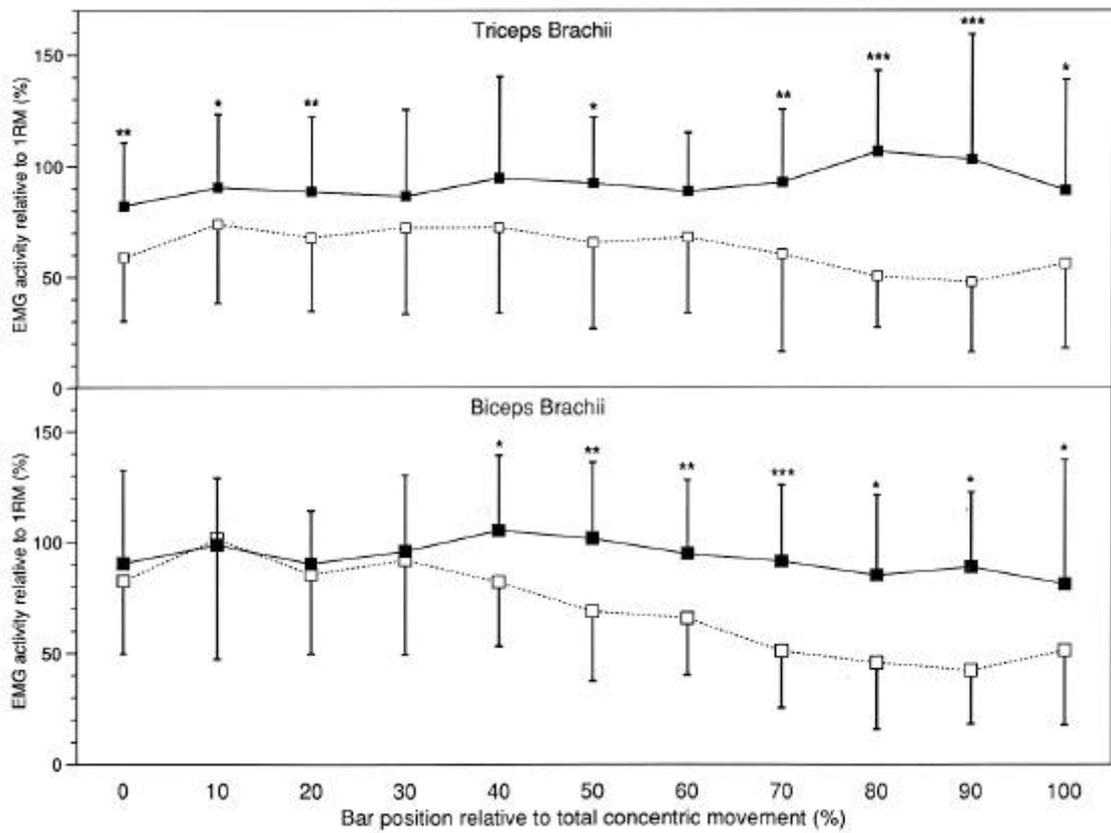
**Figure 4.3** Mean ( $\pm$ SD) vertical force in relation to total concentric bar movement for the press (G) and throw (■) conditions (\*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ).

**Table 4.2** Average EMG and peak EMG activity (highest activity over 50ms sampling period) during the concentric phase for the press and throw conditions using 45% of 1RM load. All values are expressed relative to the activity during the 1RM press. The position and time of the peak EMG activity relative to the start of the concentric phase are also provided (E.S. indicates effect size).

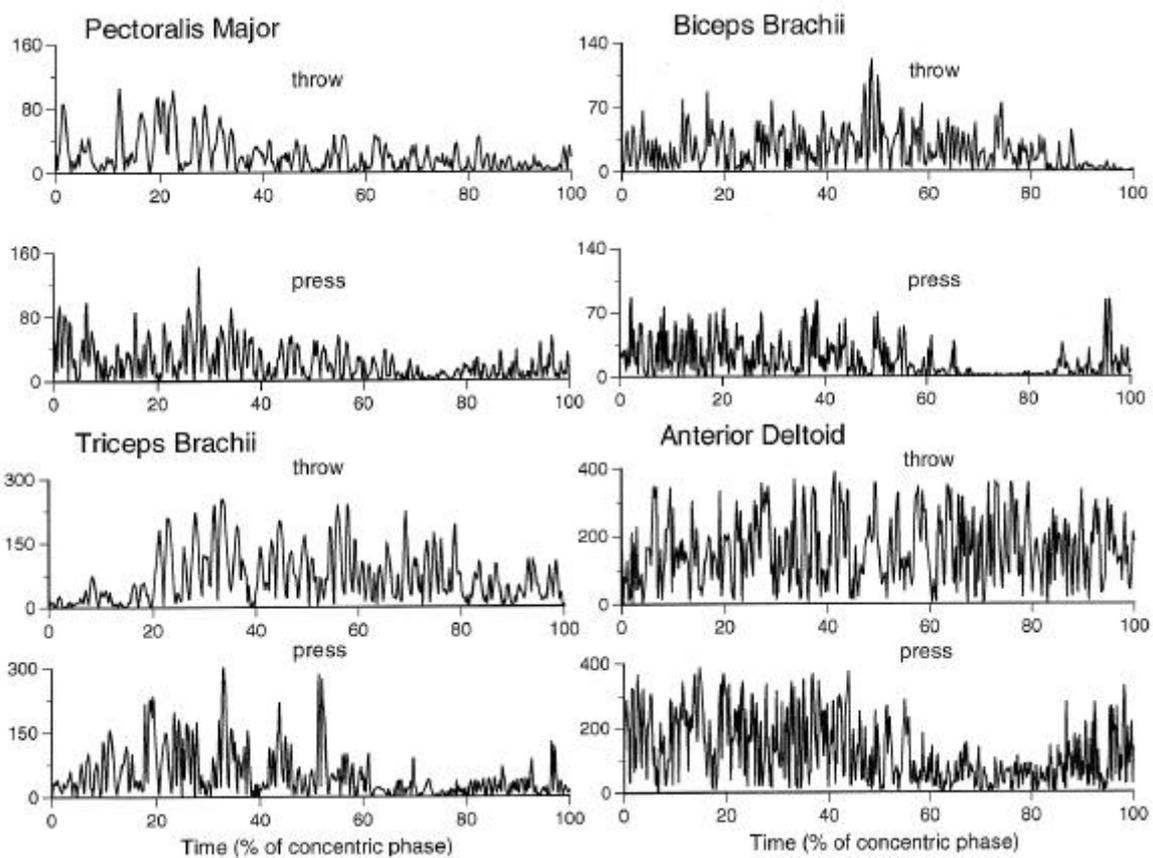
Variable	Press		Throw		Diff. %	E.S.	p
	Mean	SD	Mean	SD			
Average pectoralis EMG (% 1RM activity)	70	17	84	25	19	0.393	0.011
Average deltoid EMG (% 1RM activity)	70	22	93	29	34	0.578	<0.001
Average triceps EMG (% 1RM activity)	59	19	85	23	44	0.605	<0.001
Average biceps EMG (% 1RM activity)	65	22	83	30	27	0.399	0.005
Peak pectoralis EMG (% peak 1RM activity)	69	24	70	28	1	0.002	0.947
Position (% concentric displacement)	20	28	22	30	7	0.002	0.750
Time (ms from start of concentric)	170	150	140	150	-18	0.014	0.768
Peak deltoid EMG (% peak 1RM activity)	56	22	68	33	22	0.135	0.147
Position (% concentric displacement)	25	34	48	37	90	0.157	0.115
Time (ms from start of concentric)	180	150	260	160	44	0.111	0.192
Peak triceps EMG (% peak 1RM activity)	57	13	68	21	20	0.275	0.043
Position (% concentric displacement)	40	31	40	33	0	<0.000	0.972
Time (ms from start of concentric)	280	150	240	140	-14	0.039	0.401
Peak biceps EMG (% peak 1RM activity)	61	22	67	62	2	0.013	0.569
Position (% concentric displacement)	29	35	34	33	19	0.038	0.438
Time (ms from start of concentric)	200	190	200	150	0	0.004	0.800



**Figure 4.4** Mean ( $\pm$ SD) EMG activity (50ms integration periods) for the pectoralis major and anterior deltoid in relation to total concentric bar movement for the press (■) and throw (□) conditions (\* $p$ <0.05; \*\* $p$ <0.01; \*\*\* $p$ <0.001).



**Figure 4.5** Mean ( $\pm$ SD) EMG activity (50ms integration periods) for the triceps brachii and biceps brachii in relation to total concentric bar movement for the press (G) and throw (■) conditions (\* $p$ <0.05; \*\* $p$ <0.01; \*\*\* $p$ <0.001).



**Figure 4.6** Rectified raw EMG activity ( $\mu\text{V}$ ) of pectoralis major, anterior deltoid, triceps brachii, and biceps brachii for a representative subject performing the press versus throw movements.

## DISCUSSION

The primary results of the present study demonstrated that attempting to perform a traditional bench press movement powerfully with a 45% of 1RM load resulted, after the initial high power production, in a considerable deceleration phase prior to the bar stopping at the end of the range. This action resulted in significantly lower velocity and force output accompanied by decreased muscle activation compared with the throw condition in which the bar was accelerated throughout the range and released from the hands.

Human muscle strength can be effectively increased by traditional resistance training with slow contraction velocities (Atha, 1981; Berger, 1962; Häkkinen, Alén & Komi, 1985; Schmidtbleicher & Buehrle, 1983), however, these same methods often produce only small improvements in power production (Häkkinen & Komi, 1985b; Wilson et al., 1993) particularly in already strength trained subjects. It has been proposed that heavy resistance training is ineffective

for increasing maximal power performance because of the specific nature of the training adaptation (Häkkinen, 1989). Heavy resistance training using high resistance and slow velocities of concentric muscle contraction leads primarily to improvements in the maximal strength and the performance enhancement is reduced at the higher contraction velocities (Häkkinen & Komi, 1985a; Kaneko, et al., 1983). As a result, several authors have recommended that resistance training with both heavy and light loads be performed at fast velocities (Young & Bilby, 1993) and that the athlete attempt to move the load as rapidly as possible (Behm & Sale, 1993).

The press and the throw movements examined were very similar in terms of the preceding eccentric phase. Peak eccentric velocity and the peak force which occurred during the coupling phase were not significantly different (Table 4.1) and so it is unlikely that the differences in the subsequent concentric phase could be accounted for by differences in elastic energy storage (Komi, 1986) or stretch reflex potentiation (Gollhofer, 1987). During the concentric phase, however, greater activation of the anterior deltoid (Figure 4.4) and triceps (Figure 4.5) was evident within the first 20% of bar movement. This was reflected in the force output (Figure 4.3) which was greater for the throw movement as early as the first 10% of bar movement. The resulting bar velocity was greater for the throw throughout the movement and this difference increased to be largest at the end of the concentric phase (Figure 4.2). Therefore, although the subjects attempted to accelerate the bar as rapidly as possible in both the throw and the press, force output and EMG activity of the anterior deltoid and triceps brachii were lowered during the press even at the start of the concentric phase, perhaps in anticipation of the approaching deceleration.

Peak velocity during the press was produced 60% into the movement (Table 4.1) and the bar was then decelerated through the remaining 40%. In contrast, the bar was accelerated for 96% of the throw movement and therefore the muscles were producing tension over a greater portion of the concentric phase during the throw. The time at which peak bar velocity was attained was also significantly less for the press compared with the throw (Table 4.1) and was a result of decreasing muscle activation (Figures 4.4 and 4.5) and subsequent force output (Figure 4.3). During the press the force applied was greater than bar weight for only 370 ms out of the total concentric movement time of 590 ms, compared with 430 ms out of 440 ms for the throw (Table 4.1). Thus, the proportion of the concentric movement time as well as the total time of positive bar acceleration were significantly greater in the throw compared the press.

The kinematic and kinetic data were reflected in the EMG activities of the muscles studied. The activation of the pectoralis major was not different between the press and the throw over the first 50%-60% of the concentric movement (Figure 4.4). Therefore, it would appear that this muscle has an important role in both movements during the early phase but contributes less during

the later part of the press while continuing to be active during the throw, although at a lower level than during the 1RM press. Anterior deltoid (Figure 4.4) and triceps brachii (Figure 4.5) exhibited greater activation levels during the throw throughout the movement, even the first 0%-20% of the concentric phase. Therefore, even though the subjects were attempting to accelerate the bar maximally from the chest, EMG activity during the press was lower than during the throw. Towards the end of the range, the difference in triceps EMG activity between the throw and the press (Figure 4.5) increased. Thus it appears that this muscle contributes to a large extent to the final phases prior to release in the throw movement whereas the activation of the triceps during the press tended to decrease along with the other muscles studied.

The biceps brachii was investigated because it was expected to act as an antagonist about the elbow during the throw and press movements studied. Interpretation of the results is difficult as comparisons between the muscles cannot be made because no maximum agonist activity for the biceps was recorded. Confounding this analysis is the fact that biceps brachii does act about the shoulder joint and could therefore serve as an agonist in the two movements studied (Spence & Mason, 1979). The relative averaged biceps activity for the movement was higher during the throw (Table 4.2) and demonstrated a similar pattern of activation over the concentric phase to the pectoralis major. It was expected that activity would increase in the biceps when the bar was being decelerated, however, this was not observed (Figure 4.5). This result may have been due to 1. the biceps' role as an agonist about the shoulder joint; 2. a possible stabilization role throughout both movements; 3. Coactivation of the biceps brachii during the throw to stiffen the elbow joint during the higher velocity movement; or 4. a reflection of a similar activation pattern during the 1RM press which has masked any differential activation pattern during the throw and press movements with the 45% load.

The investigation of the bench press by Elliott et al. (1989) found the deceleration phase to be 51.7% of the concentric movement time when lifting an 81% of 1RM load. In the present study using a 45% of 1RM load and a rapid press movement, the deceleration phase was 40% but the force output during the deceleration phase was reduced to only a fraction of the bar weight. The previous study (Elliott et al., 1989) found the minimum force during the deceleration phase to be only some 100-150 N below bar weight. Therefore when performing rapid bench presses with a light load, the deceleration phase involves a considerable unloading of the muscles which is much greater than if a heavier load (80%-100%) is simply lifted with no attempt to maximise movement velocity.

During the bench press with a light load the deceleration phase was shorter (40%) compared with the slow bench press with heavy load (51.7%; Elliott et al., 1989). It is suggested that when

attempting to perform a powerful press movement and maximise bar velocity, the subjects reduced the deceleration phase to maximise the impulse produced, however, as the bar was required to stop at the end of the range, the deceleration forces increased markedly as a result.

On examination of the force output during the press and throw movements, it is interesting to note that the force is maintained throughout the throw movement and only decreases at the point of release (Figure 4.3). During the later stages of the throw the muscles are shortening at a fast velocity and a decrease in force output could be expected (Hill, 1938; Kaneko, et al., 1983; Faulkner, et al., 1986). However, the mechanical advantage of pectoralis major and anterior deltoid are increasing and this may explain the maintenance of force output. Therefore, the use of ballistic, powerful movements such as the bench throw may represent a method for overloading the neuromuscular system effectively throughout the range of motion.

Finally, the results of this research indicate that the velocity (Figure 4.2) and force (Figure 4.3) curves for the throw are more similar than the press movement to that exhibited during typical powerful actions such as jumping, throwing, and striking (Kreighbaum & Barthels, 1985). For the throw, acceleration is produced throughout the range resulting in a high end velocity while the press involves a phase lasting some 40% of the movement when the neuromuscular system is reducing the velocity of the bar.

## CONCLUSIONS

In conclusion, the results of this study suggest that given the inherent limitations of traditional resistance training (i.e. the load must stop at the end of the concentric movement), attempting to perform the traditional bench press in a powerful manner with a light load will result in reduced velocity, force output and muscle activation compared with a bench throw. In the throw movement, the muscles were active throughout the concentric phase, maintaining a high force level and resulting in the load being accelerated over the entire range of motion, a higher velocity of movement and a minimal deceleration phase providing superior loading conditions for the neuromuscular system. This type of movement would also appear more specific to the powerful movements typically used in sports performance. To what extent repeated loading of this type during power training would also result in greater training-induced adaptations in the neuromuscular system compared with the traditional loadings needs to be examined in the future.

# ***Chapter 5***

## **EXPERIMENT THREE**

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### **INFLUENCE OF LOAD AND STRETCH SHORTENING CYCLE ON THE KINEMATICS, KINETICS AND MUSCLE ACTIVATION DURING POWERFUL UPPER BODY MOVEMENTS**

#### **INTRODUCTION**

Many sport and work activities require powerful movements of the upper body. Although maximal power has been extensively studied in lower body activities such as vertical jumping (Bosco and Komi, 1979; Häkkinen et al., 1986; Häkkinen and Komi, 1985a; Häkkinen and Komi, 1985b; Komi and Bosco, 1978; Komi, 1984; Schmidtbleicher and Buehrle, 1983; Wilson et al., 1993; Young and Bilby, 1993), there is a paucity of research examining such movements in the upper body (Bober et al., 1980; Gollhofer et al., 1987; Van Leemputte et al., 1983).

The relationship between force, velocity and power output has been studied in bundles of muscle fibers (Faulkner et al., 1986; Hill, 1938), single joint movements (Kaneko et al., 1983; Moritani et al., 1987; Perrine and Edgerton, 1978), and multijoint movements such as vertical jump (Bosco and Komi, 1979; Komi and Bosco, 1978). The majority of prior research concurs that the force capability of muscle in concentric actions decreases with increasing velocity of shortening and maximal power output is produced at approximately 30% of maximum isometric force and approximately 30% of maximum shortening velocity (Edgerton et al., 1986; Faulkner et al., 1986; Hill, 1938; Kaneko et al., 1983; Moritani et al., 1987).

Most maximal power activities involve a preparatory movement, which places the agonist

muscles in a lengthened position prior to the subsequent concentric action. This movement sequence has been termed a stretch shortening cycle (Komi, 1984) and has been shown to enhance the concentric muscle action due to recovery of stored elastic energy and increased agonist muscle innervation as a result of the stretch reflex (Bosco and Komi, 1979; Bosco et al., 1982; Ettema et al., 1990; Gollhofer and Kyröläinen, 1991; Häkkinen et al., 1986; Komi, 1984; Schmidtbleicher, 1988; Schmidtbleicher et al., 1988). The influence of the stretch shortening cycle (SSC) in upper body movements has received limited attention (Bober et al., 1980; Elliott et al., 1989; Gollhofer et al., 1987; Van Leemputte et al., 1983).

Bober et al. (1980) have examined SSC movements in the upper body, however, this study increased the stretch load on the muscle by increasing the velocity of a swinging pendulum. The subject had to brake the pendulum and then push for maximal power output against the same load. Similar stretch shortening cycle potentiation of performance was found for this upper body movement as has been measured for the lower body (Bosco and Komi, 1979). Gollhofer et al. (1987) have investigated the effects of fatigue on SSC performance of the elbow extensors. Both purely concentric and SSC test movements were performed, however, the resulting performances of each were not compared.

The purposes of this study were to: 1) Investigate the effect of load on the movement velocity, force output, power output and muscle activity during maximal effort ballistic bench throws; 2) Assess the influence of the stretch shortening cycle on upper body maximal power production. The bench press/throw movement was chosen because it is a multi-joint exercise commonly used in resistance training, sport and work performance and because it is analogous to the squat exercise commonly used to assess SSC performance for the legs.

## **METHODS**

### ***Subjects***

Seventeen male exercise science students volunteered to take part in the study. All subjects had been weight training for their own conditioning purposes for a minimum of six months and could bench press at least their own body weight. The subject's mean ( $\pm$ S.D.) age, height and weight were  $20.6\pm 1.9$  yrs,  $1.79\pm 0.06$  m and  $83.7\pm 8.2$  kg respectively. The study was approved by the Ethics Committee of Southern Cross University, and all subjects signed an informed consent document prior to the commencement of testing (Appendix E).

## **Testing Procedures**

Testing was conducted over two sessions separated by four days. During the first testing session the subject's one repetition maximum (1RM) load for the bench press was determined according to the procedures of Young and Bilby (1993) using the Plyometric Power System (PPS) (Wilson et al., 1993). The 1RM was tested using a stretch shortening cycle movement with no pause at the bottom. The subjects lowered the bar to the chest but were not permitted to “bounce” the bar off the chest. They were required to press the bar to full elbow extension to record a successful lift. The subject's age, weight and height were also recorded during this session. The subject then completed a number of bench throws of two types using a load of 45% of 1RM. The first movement was a stretch shortening cycle throw (SSC) for which the subject was instructed to lower the bar rapidly to the chest and immediately throw it upwards for maximum height. Second, a concentric only throw (CO) for which the bar was positioned 1cm above the subject's chest supported by the bottom stops on the PPS. The subject was then instructed to perform a purely concentric push for maximum height. As it was unlikely that the subjects had performed bench throws previously, these throws served as familiarisation for the second testing session.

The second test session began with a general warmup involving two sets of 10 bench presses at a submaximal load of 45% of 1RM followed by 5 minutes of chest and tricep static stretches. The subject was then instructed to lie on the bench of the PPS such that the bar crossed the chest at the level of the nipples. To allow for comparison of EMG recorded during later trials, the subject completed a single SSC bench press with a load equal to his previously determined 1RM. All subjects could complete the 1RM trial. The two movements, SSC and CO, were then tested at each load of 15%, 30%, 45%, 60%, 75% and 90% of this 1RM. Three trials were completed for each condition with 3 minutes rest between each trial. The braking mechanism on the PPS (*see* Chapter Four) stopped the bar at the top of its flight so that the subject did not have to catch the bar after the throw.

The subject was not permitted to raise the shoulders off the bench, no pause was allowed between the eccentric and concentric phases of the SSC throws, and the subject could not “bounce” the bar off the chest. The subject was instructed to lower the bar at a self-selected velocity as far as possible during the eccentric phase without contacting the chest. If the bar contacted the chest or the safety stops, the trial was discarded and repeated after a three minute rest. Further, if the subject applied force to the bar or performed a counter movement prior to the CO throws the trial was rejected. During the 1RM press and all throws, the subject was required to maintain the shoulders in a 90 degree abducted position to ensure consistency of shoulder and elbow angles and movement throughout the testing. Immediately before each trial the force plate amplifiers were zeroed to the

combined weight force of the subject and bench. The order of presentation of the loads was randomised between subjects and the order of SSC and CO conditions alternated between each load. During each throw, bar displacement data from the PPS, vertical force from a force plate, and EMG data were collected and stored for later analysis.

## ***Equipment***

### **Plyometric Power System**

The PPS (Norsearch Limited, Lismore, Australia) allows resistance training movements such as bench press and squat to be done in a dynamic, ballistic manner and has been described in Chapter Four. In this study the bar was thrown from the chest while lying horizontal on a bench. The machine allowed only vertical movement of the bar, and metal stops limited the lower travel of the bar with an accuracy of 0.01 m. This prevented the bar from contacting the subject should the bar be lowered too far during the eccentric phase. Linear bearings attached to either end of the bar allowed it to slide up and down two steel shafts with a minimum of friction.

As the bar moved, chain attached above and below, drove a sprocket at the top of the PPS. This sprocket in turn rotated a rotary encoder (Omron Corporation, Japan). As a result, the encoder produced a 5 volt (TTL) pulse for each 0.001 m of bar movement. These pulses along with a TTL signal indicating movement direction were fed into a CTM05 counter timer board (Computer Boards, Mansfield, MA) installed in a 80386DX computer running MSDOS. The counter timer card was capable of measuring pulse frequencies of up to 1MHz and time events with an accuracy of 10 microseconds. The system was calibrated prior to each testing session by counting the total number of pulses produced as the bar was moved through its full vertical range of 2.8 m. The rotary encoder system and its validity and reliability are detailed in Chapter Three.

One-way sprag clutches ensured that only the sprockets and encoder rotated during upward bar movement, however, when the bar began its downward movement at the top of the throw, the clutches engaged and spun a steel shaft which traversed the top of the PPS. An electromagnetic brake attached to this shaft allowed the bar to be stopped at the top of its movement range after being thrown (*see* Chapter Three).

### **Force Measurement System**

Vertical ground reaction force was measured by means of a bench conforming to International Powerlifting Guidelines which was isolated on a Kistler force platform (Type 9287, Kistler, Switzerland) and attached by four bolts. The signals from the charge amplifiers were passed

to a CIO-DAS16 analog to digital card (Computer Boards, Mansfield, MA) in a 80386DX computer running MSDOS. The digital data were stored on computer disk for later analysis. The force measurement system was calibrated prior to each testing session.

### **Electromyography**

During all throws each subject had four silver/silver chloride surface electrode modules (Quantec, Brisbane, Australia) attached over the sternal portion of the pectoralis major, the anterior deltoid, and the belly of the long head of triceps brachii. All electrodes were attached to the subject's right side. Each electrode module consisted of two active electrodes and a third ground electrode all equi-distant at 2 cm. The active electrodes were aligned parallel with the fibers of the muscle under investigation. Before electrode application, each site was shaved, cleansed with alcohol, gently abraded and a small amount of conductive gel applied to each electrode. The impedance between each electrode pair was then measured to ensure resistance was below 5k $\Omega$ . Preamplifiers (Quantec, Brisbane, Australia) were incorporated into the electrode modules with the signal being further amplified using amplifiers (Quantec, Brisbane, Australia) with a low pass filter setting of 1 kHz and a high pass filter at 3 Hz. The amplified myoelectric signals were collected using an 80386DX computer running MSDOS and a CIO-DAS16 analog to digital card (Computer Boards, Mansfield, MA). The digitized data were stored on computer disk for later analysis. Bar displacement, vertical ground reaction force and EMG data were sampled simultaneously at a frequency of 876 Hz for each channel.

### **Data Analysis**

The displacement time data was filtered using a fourth order Butterworth digital filter with the optimal cut-off frequency (14 Hz) determined using the Jackson "knee" method (Jackson, 1979). Initiation of the concentric phase of the SSC throws was determined as the time when the bar velocity changed from positive to negative (bottom of movement). For the CO throw the start of the concentric phase was the point at which the vertical force started to increase. This was defined as the point after which the force increased for each of the next 20 consecutive samples (23 ms). The end of the concentric phase for both throws was the point at which the vertical force decreased to below zero i.e. the bar left the hands. The following variables were then calculated for the concentric phase: height thrown, average velocity, force, and power; peak velocity, force and power, and the duration of the concentric phase

The start of the eccentric phase for the SSC throws was determined as the point after which the bar position was successively decreasing (i.e. the bar was being lowered) until the start of the

concentric phase. For the eccentric phase of the SSC throws, time duration, peak and average velocity, force, and power were calculated. The peak eccentric velocity, and the force and velocity 50 ms and 100 ms prior to the start of the concentric phase were also calculated. EMG data was quantified in two ways. The mean EMG was calculated by full wave rectification followed by integration with respect to time over the concentric phase, then divided by the time of the concentric phase. Peak EMG was calculated by integrating the rectified EMG over consecutive 50 ms time periods and determining the highest activity level. For comparison between loads and movement type, the peak and mean EMG values were normalised relative to the peak and mean activity recorded during the 100% 1RM trial. In addition the average EMG 100-50 ms before, 50-0ms before, 0-50ms after and 50-100ms after the start of the concentric phase were also calculated. Fast Fourier Transformation (FFT)(Winter, 1990) was applied to determine the mean and median frequencies of the power spectrum over the entire concentric phase for each of the muscles studied. EMG data from the whole concentric phase was analysed by the FFT for two reasons. First, to account for quantitative and qualitative changes in EMG with changing muscle length. Second, to ensure that sufficient data points were available for analysis by the FFT particularly during the trials with lighter loads in which the average concentric movement time was only 388 ms.

### ***Statistical Analysis***

Means and standard deviations were determined for each variable and condition. The results for mean velocity, peak velocity, mean force, peak force, mean power, mean and peak EMG were compared using a multivariate analysis of variance with repeated measures. The independent variables were percentage load and movement type. If a significant effect of load on a dependent variable was found, one-way ANOVA followed by Scheffè post hoc comparisons were performed to determine which of the loads produced significantly different results. Statistical significance was accepted at an alpha level of  $p \leq 0.05$ .

## **DELIMITATIONS**

The samples chosen for this study were limited to adult males who were experienced weight lifters.

The analysis of kinetics, kinematics, and muscle activation was limited to the bench throw movement.

Only four muscle groups on the right side of the body were analysed using myoelectric techniques (pectoralis major, triceps brachii, anterior deltoid, and biceps brachii).

Only six loads (15%, 30%, 45%, 60%, 75%, and 90% of 1RM) were used to examine the force,

velocity, power and muscle activation during ballistic movements.

## LIMITATIONS

In addition to limitations arising from the above:

Surface myoelectric techniques were used to estimate underlying muscle function particularly gross muscle action through iEMG. Increases in iEMG cannot be specifically attributed to increases in recruitment and/or rate coding or perhaps some other factors (e.g. temperature) with certainty, particularly the relative contributions of each mechanism.

The mean and median power frequency of the surface EMG was used as an indicator of relative recruitment of slow and fast motor units.

Force output was measured through the bench rather than directly as the force exerted by the hands on the bar.

When comparing the magnitude of the iEMG across different loads each will involve different movement velocities, which would effect the magnitude of the recorded EMG signal. Therefore it is not possible to determine if the changes in iEMG are due to the load effect or the changing contraction velocity.

The maximum sampling frequency, which could be achieved with the data collection system used, was 876 Hz.

## RESULTS

The mean ( $\pm$ SD) 1RM bench press for the subjects was  $104 \pm 16$  kg. Both load and movement-type effects were observed for many of the variables measured during the throws.

### ***The Effect of Load***

Height thrown decreased with increasing load in both movement types (Table 5.1). Average and peak concentric velocity decreased with increasing load (Figures 5.1 and 5.2). Average and peak force increased with increasing load (Figures 5.1 and 5.4). The load thrown also had a significant effect on the mean power with the highest mean power output being produced at the 30% ( $563 \pm 104$ W) and 45% ( $560 \pm 86$ W) loads (Figures 5.1 and 5.6). Peak power output was maximised at the 15% and 30% loads and decreased with increasing load (Figures 5.1 and 5.6). The time of the concentric movement increased with increasing load (Table 5.2). There was no significant effect of load thrown on the mean deltoid EMG, peak deltoid EMG, or mean pectoralis

major EMG. There was a significant effect on peak pectoralis major EMG (Figure 5.9), mean triceps EMG, and peak triceps EMG. The general trend was for EMG activity in these muscles to increase with increasing load used. Both mean and median EMG frequency of the deltoid and pectoralis major muscle (Figure 5.9) decreased significantly with increasing load for the SSC throws. There was no effect of load on the frequency of triceps EMG for the SSC throws. For the CO throws, no effect of load on frequency of EMG was observed for any of the muscles examined. There was no effect of load on the EMG activity 50ms or 100ms before or after the start of the concentric phase for either of the throws.

**Table 5.1** Height of throw measured from the point at which the bar left the hands to the top of the bar movement. The heights thrown for the SSC throws, CO throws and the pooled data are shown.

<b>Height of Throw (m)</b>			
<b>(Mean±SD)</b>			
<b>Load</b>	<b>SSC</b>	<b>CO</b>	<b>Mean</b>
15%	0.740±0.114	0.736±0.089	0.738±0.102
30%	0.361±0.050	0.358±0.054	0.360±0.052
45%	0.229±0.051	0.224±0.034	0.226±0.043
60%	0.133±0.025	0.151±0.038	0.142±0.032
75%	0.078±0.023	0.083±0.014	0.081±0.019
90%	0.039±0.026	0.040±0.023	0.039±0.025
<b>Mean</b>	0.263±0.048	0.265±0.042	0.264±0.045

**Table 5.2** Concentric movement time measured from the start of the upwards movement to the point at which the bar left the hands. The times for the SSC throws, CO throws and the pooled data are shown.

<b>Concentric Movement Time (ms)</b>			
<b>(Mean±SD)</b>			
<b>Load</b>	<b>SSC</b>	<b>CO</b>	<b>Mean</b>
15%	327±36	450±50	388±75
30%	401±39	545±44	470±84
45%	492±57	691±44	591±113
60%	631±78	877±88	754±149
75%	935±277	1333±203	1128±314
90%	1541±430	2227±583	1850±605
<b>Mean</b>	721±467	985±633	850±568

### ***SSC Versus CO Throws***

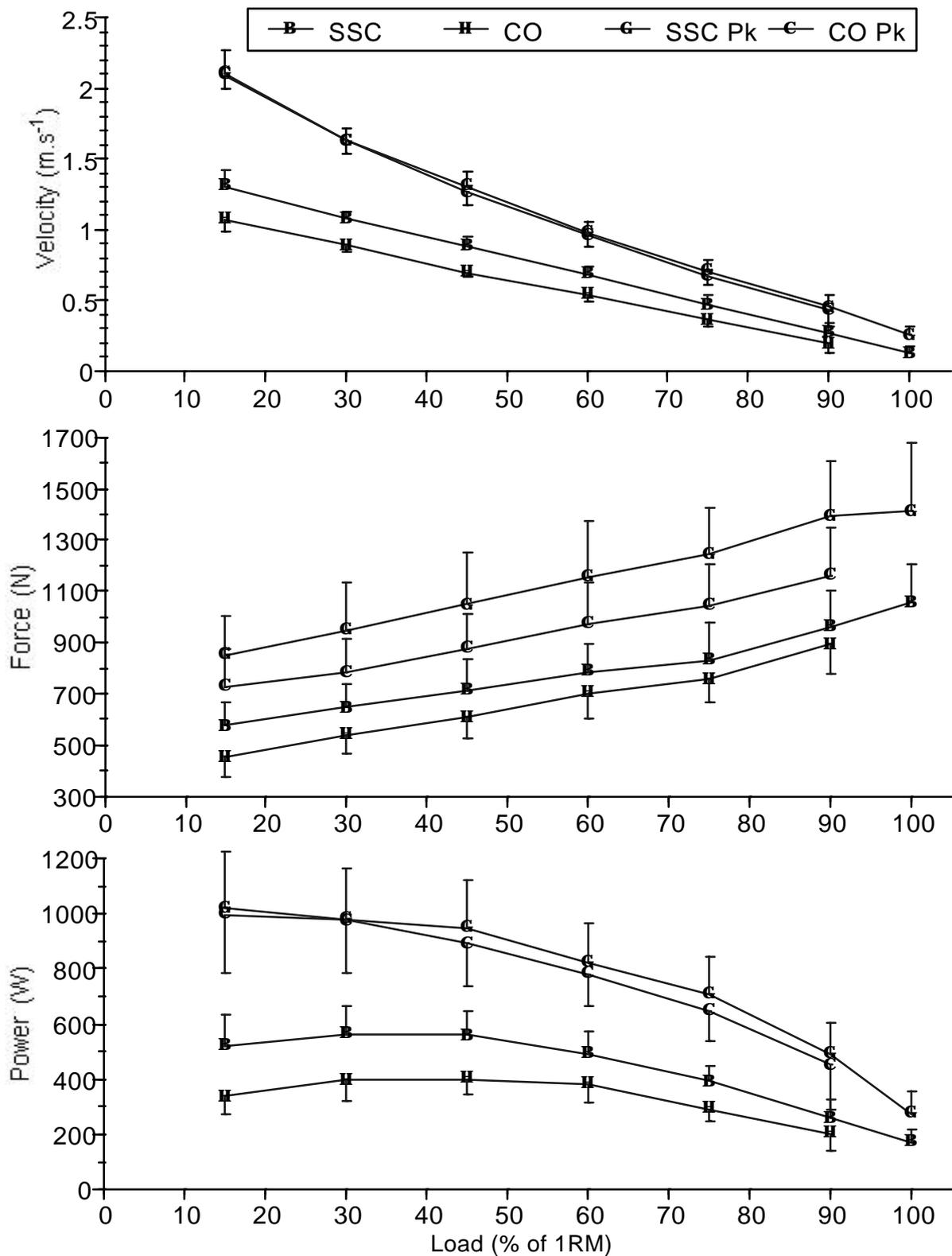
The average velocity was higher for the SSC throw compared with the CO throw at all loads (Figure 5.1). However, there was no difference between the height thrown for the SSC and CO throws at any load (Table 5.1) and the peak velocity produced was not significantly different between the two throws except for the 75% load (Figures 5.1 and 5.3). Both average and peak force were greater for the SSC compared with CO throws at all loads (Figure 5.4). Also, average power output was significantly higher for the SSC compared with the CO throws at all loads (Figure 5.7). The time duration of the concentric phase was significantly longer for the CO throws (Table 5.2).

There was no difference in peak or mean pectoralis major EMG, peak or mean deltoid EMG, or peak triceps EMG between the SSC and CO throws. However, mean triceps EMG activity was significantly higher for the SSC throws than the CO throws. EMG activity was significantly higher for the pectoralis major and triceps 50 ms after, and also for the triceps 100 ms after the start of the concentric phase for the SSC compared with the CO throws.

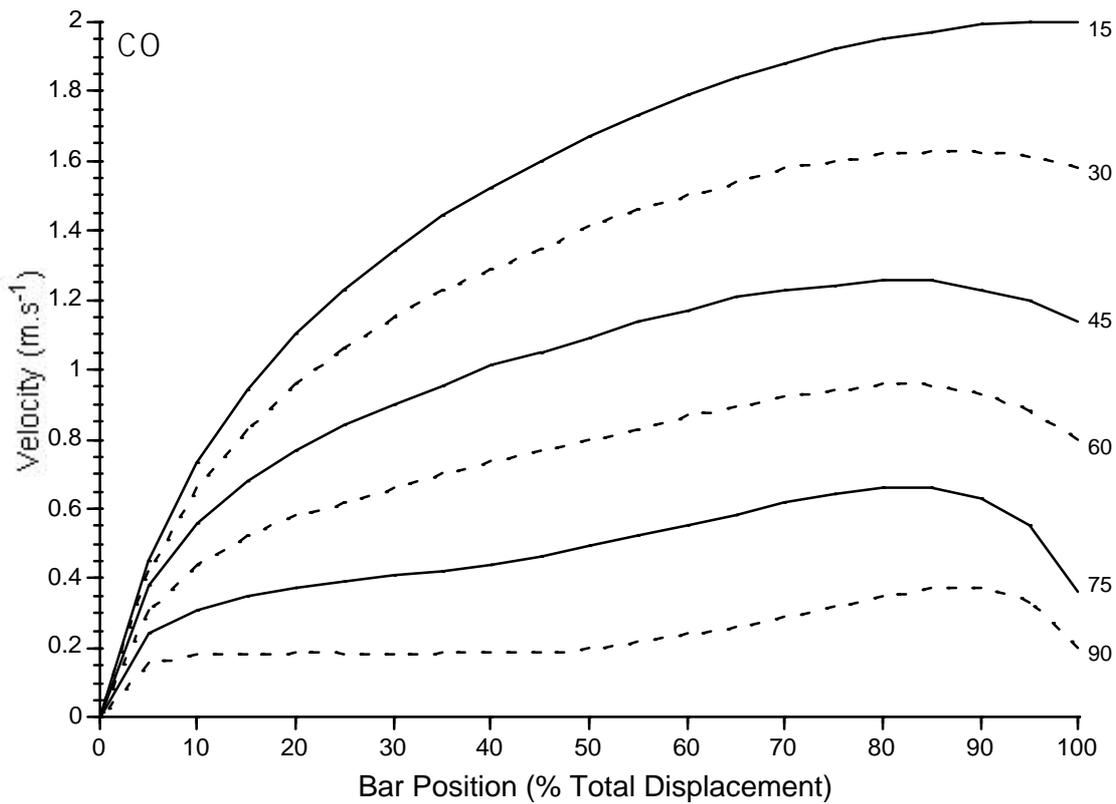
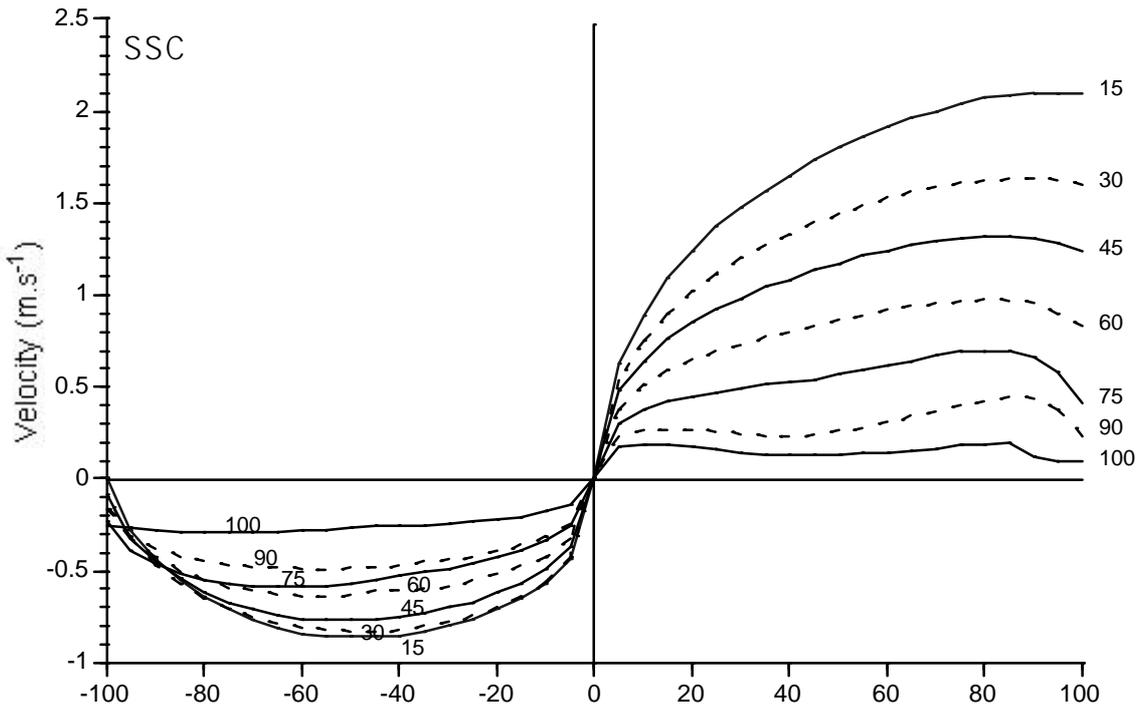
### ***Eccentric Phase***

Load also influenced the eccentric phase of the SSC throws with the peak velocity decreasing with increasing load (Figure 5.2). Also, the time and bar position at which this peak

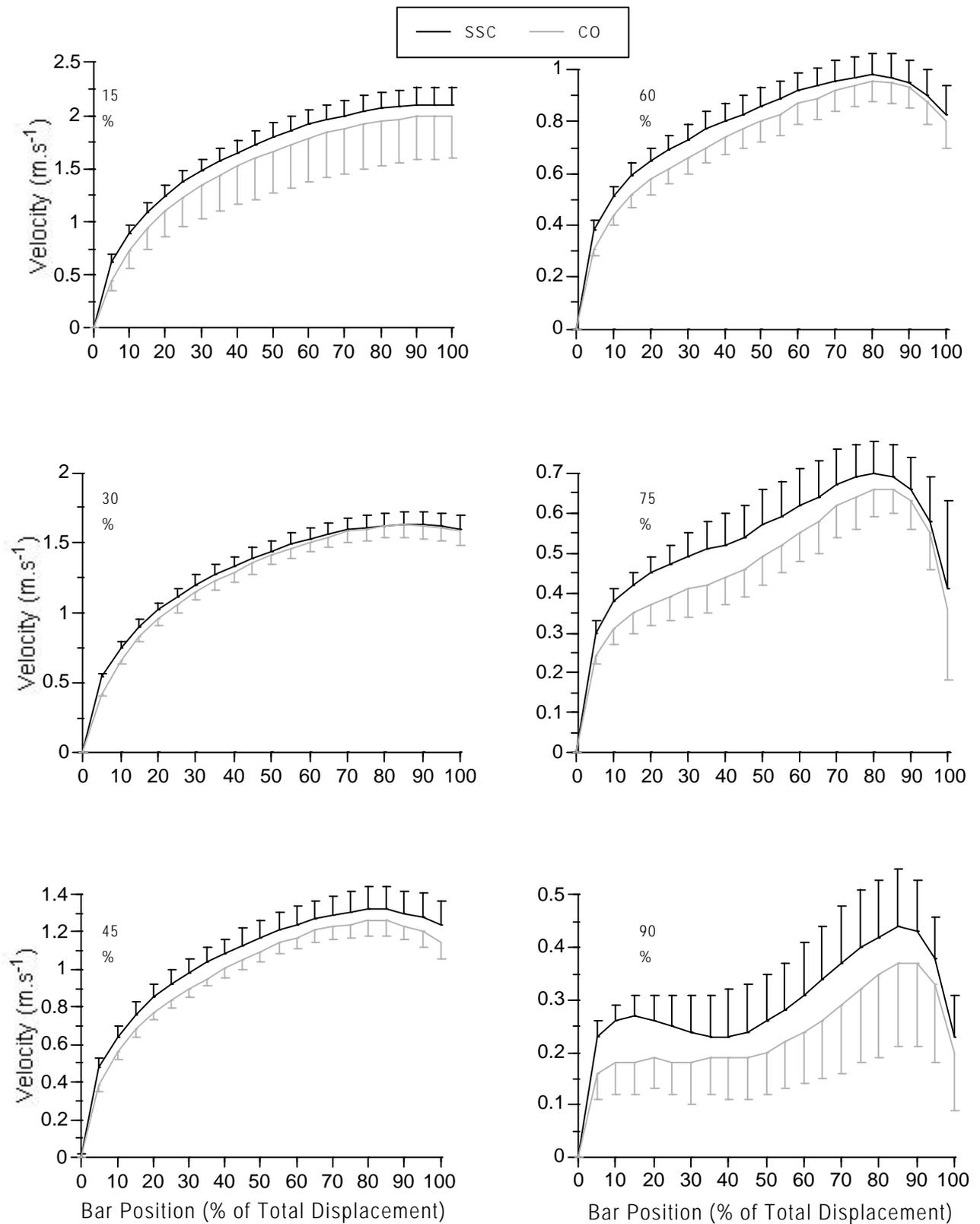
occurred moved closer to the end of the eccentric phase, the lighter the load being thrown. The velocity of the bar during the final stages of the eccentric phase, 50 ms and 100 ms before the start of the concentric phase, decreased with increasing load (Figure 5.8). The total time duration of the eccentric phase was not effected by load. Average force over the eccentric phase increased with load (Figure 5.4) as did the force measured 50 ms and 100 ms prior to the start of the concentric phase (Figure 5.8). Load did not have any effect on the peak EMG activity during the eccentric movement, or the EMG activity 50 ms or 100 ms before the end of the eccentric phase for any of the muscles examined.



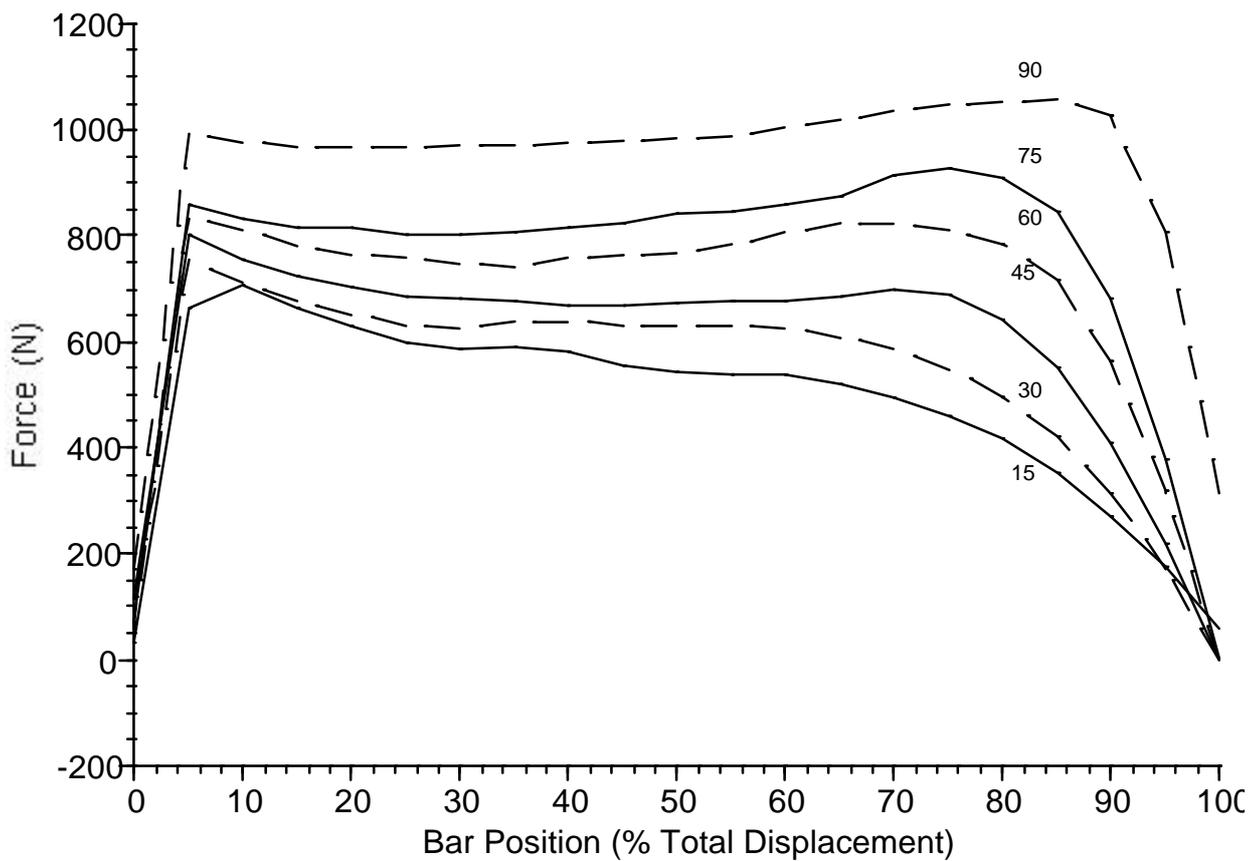
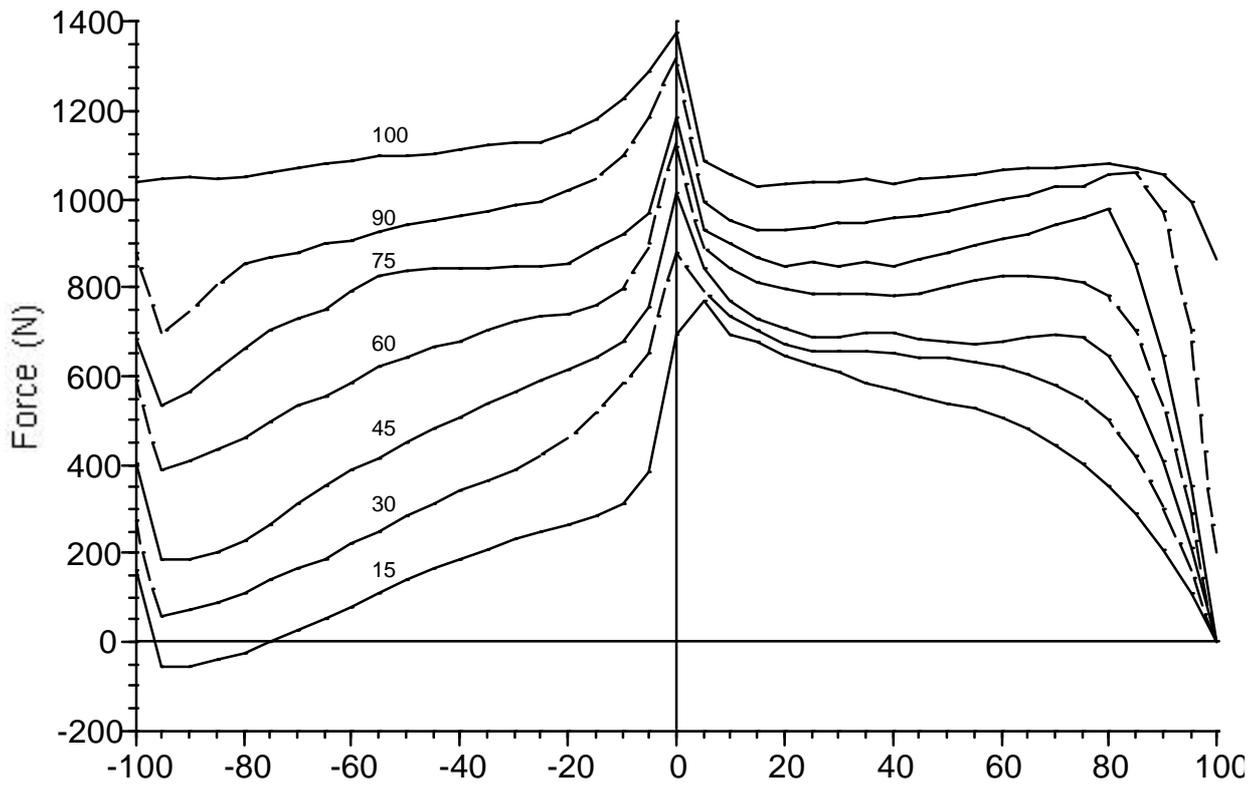
**Figure 5.1** Peak and average concentric velocity, force and power produced at loads of 15% to 100% of 1RM during bench throws. Group means are shown with error bars indicating 1 SD.



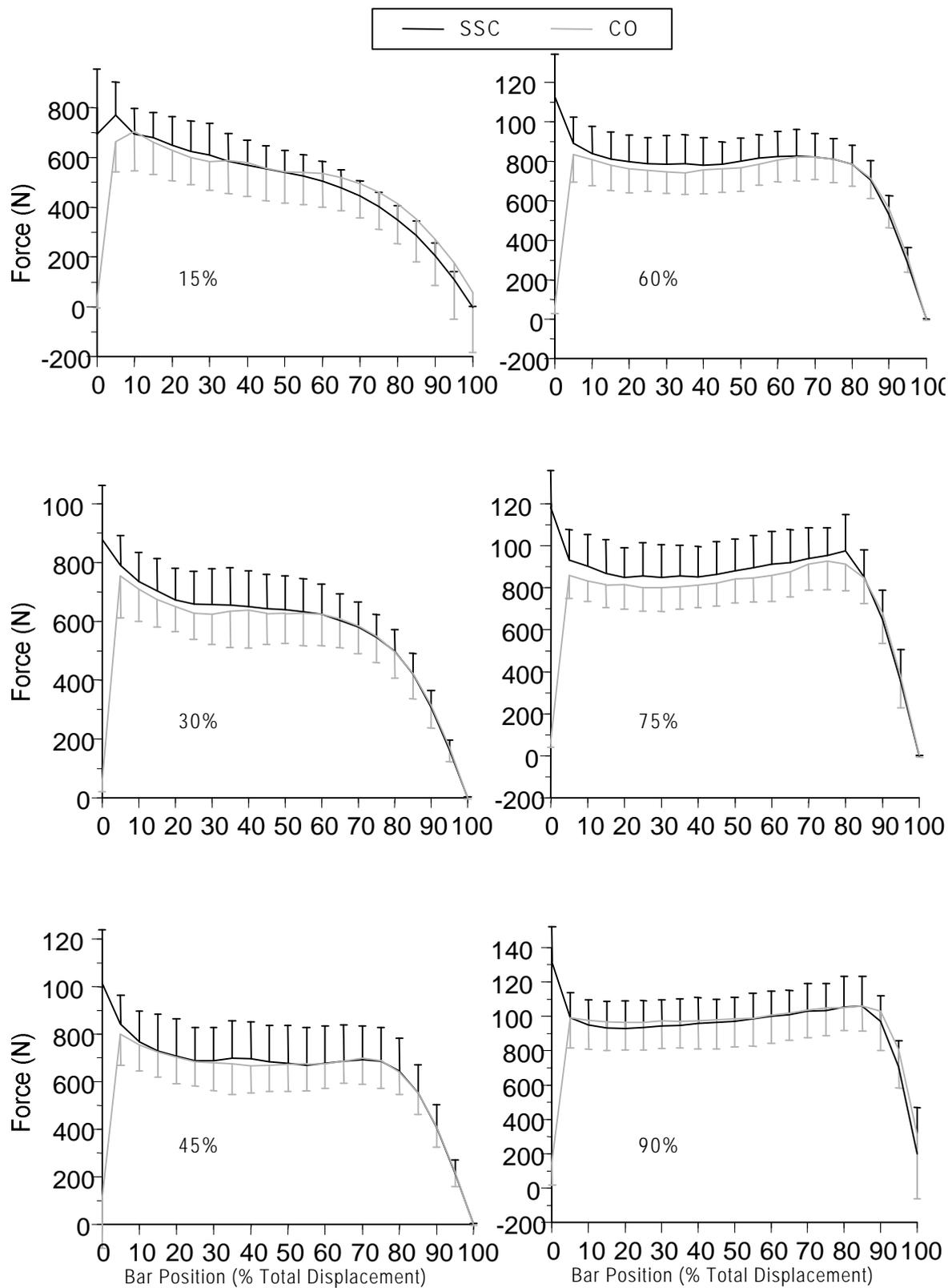
**Figure 5.2** Effect of load on average bar velocity during the performance of SSC and CO throws. Bar position is expressed as a percentage of total concentric or eccentric displacement. Data is averaged across all subjects.



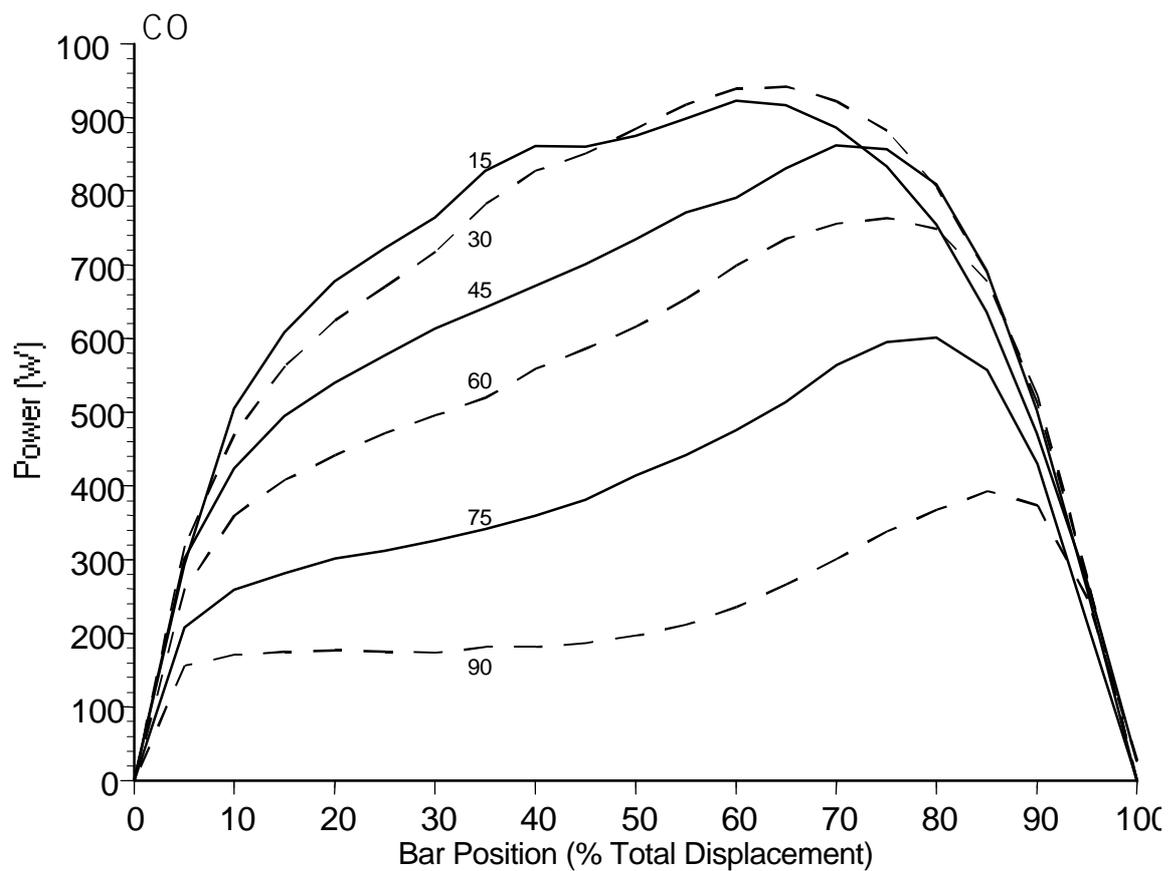
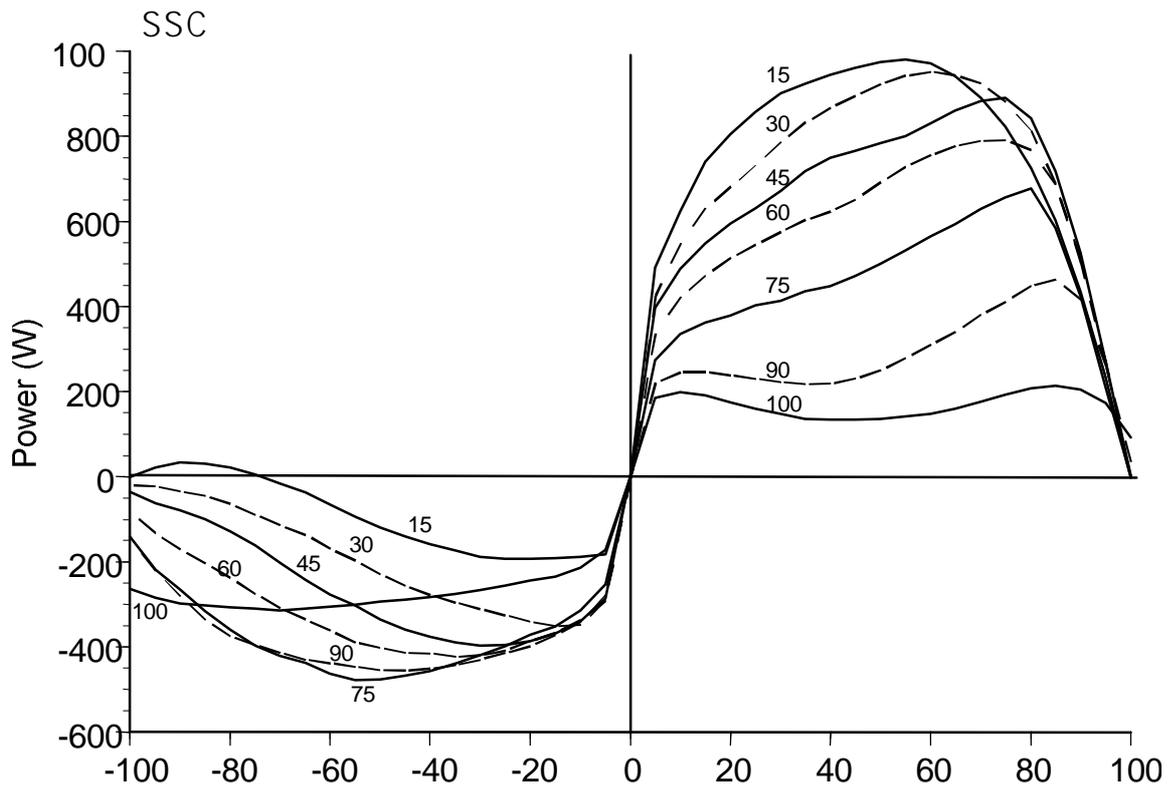
**Figure 5.3** Comparison of average bar velocity for SSC and CO throws with different loads. Bar position is expressed as a percentage of total concentric or eccentric displacement. Group means are shown with error bars indicating 1 SD.



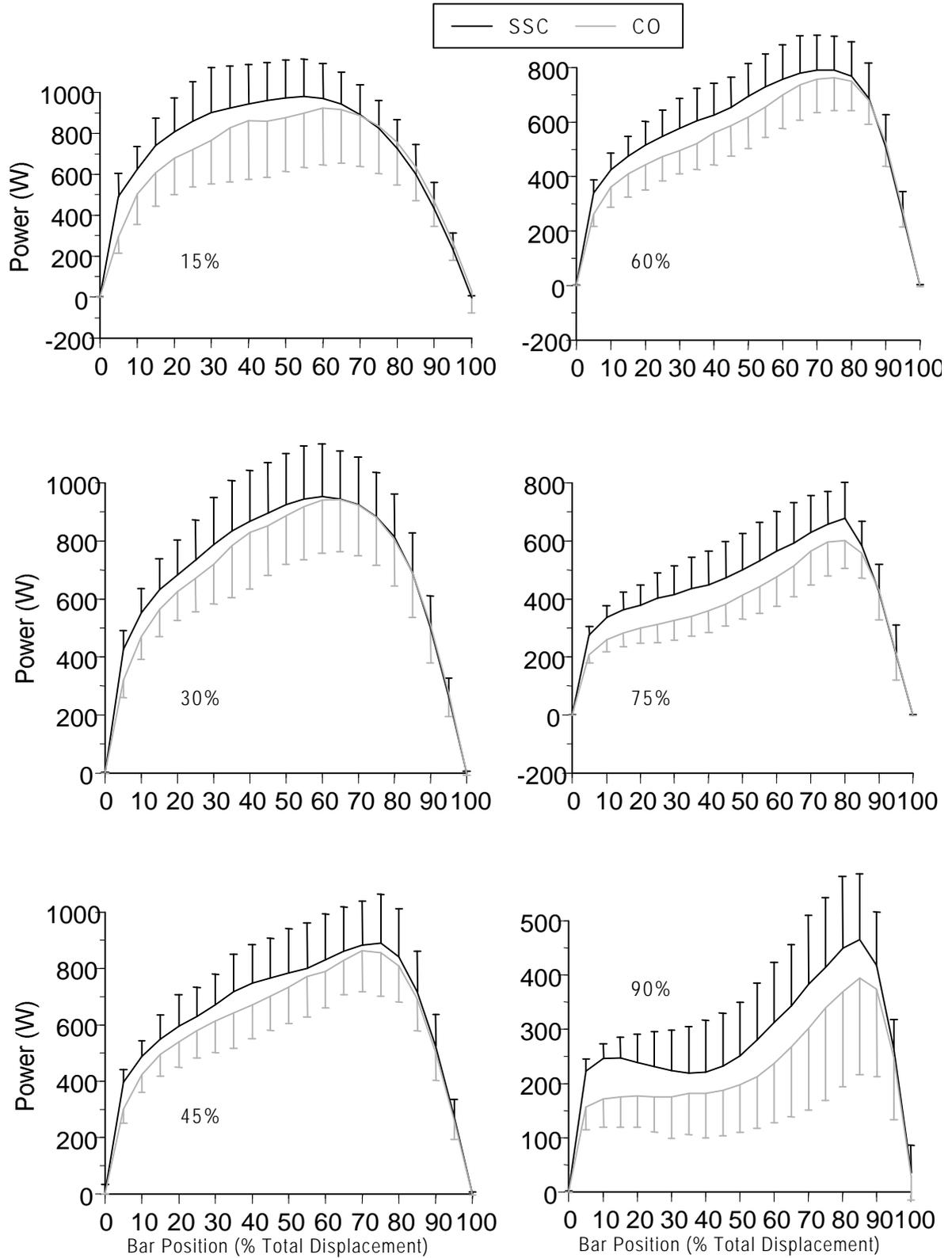
**Figure 5.4** The effect of load on average vertical force during the performance of SSC and CO throws. Bar position is expressed as a percentage of total concentric or eccentric displacement. Data is averaged across all subjects.



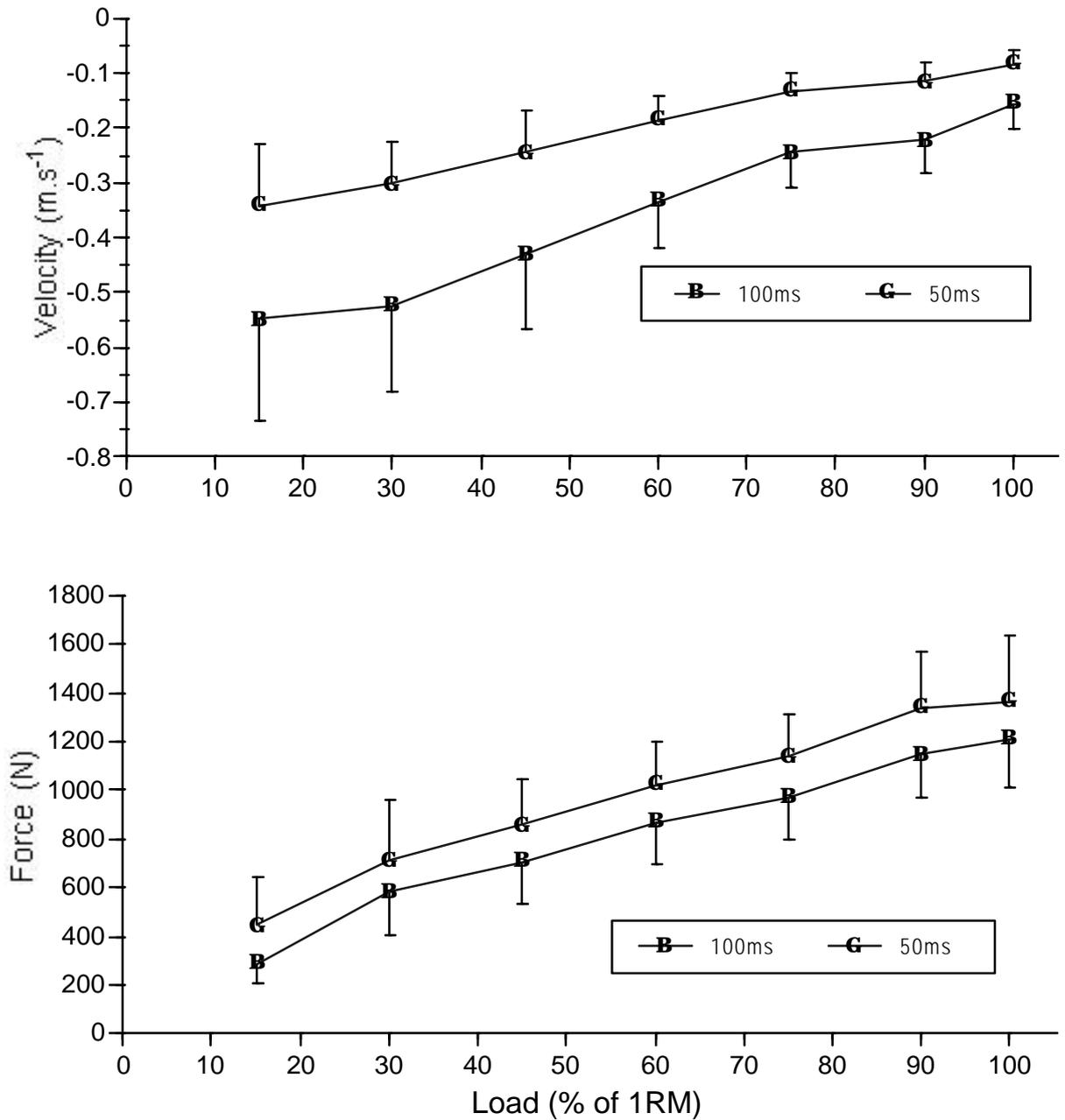
**Figure 5.5** Comparison of average vertical force for SSC and CO throws with different loads. Bar position is expressed as a percentage of total concentric or eccentric displacement. Group means are shown with error bars indicating 1 SD.



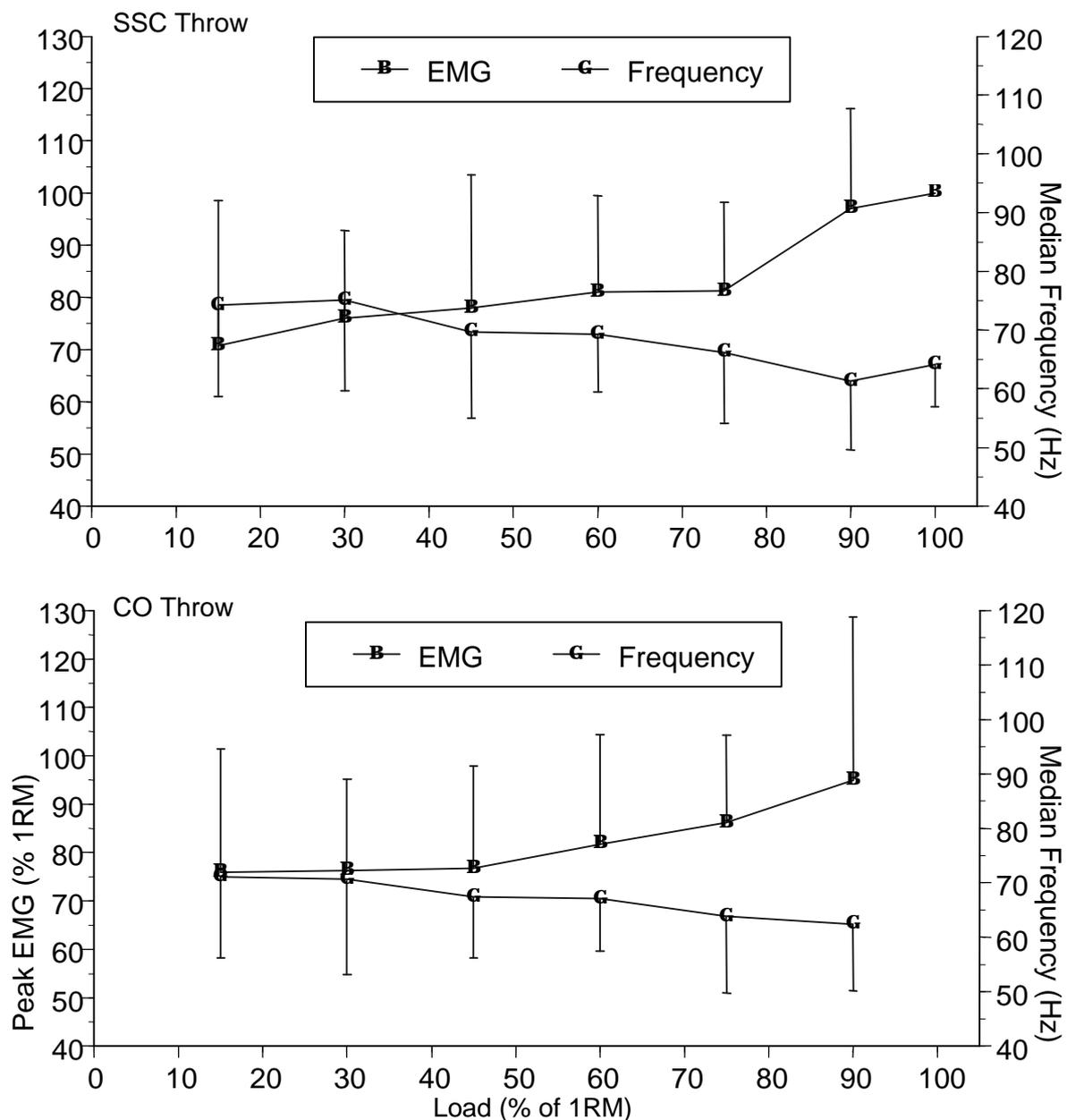
**Figure 5.6** The effect of load on average power output during the performance of SSC and CO throws. Bar position is expressed as a percentage of total concentric or eccentric displacement. Data is averaged across all subjects.



**Figure 5.7** Comparison of average power output for SSC and CO throws with different loads. Bar position is expressed as a percentage of total concentric or eccentric displacement. Group means are shown with error bars indicating 1 SD.



**Figure 5.8** Vertical force and bar velocity 100 ms (**B**) and 50 ms (**G**) before the end of the eccentric phase of the SSC throws. Note that the negative velocity denotes downwards or eccentric direction. Group means are shown with error bars indicating 1 SD.



**Figure 5.9** Peak EMG, expressed as a percentage of the activity recorded during the 1RM trial, and median frequency of the pectoralis major during the concentric phase of the SSC and CO throws. Group means are shown with error bars indicating 1 SD.

## DISCUSSION

The relationship between the load moved, the velocity of movement, and the power output during the powerful upper body movements used in this study was similar to that determined for isolated muscle (Hill, 1938), using isokinetic dynamometry (Perrine and Edgerton, 1978) and studies using a load of constant mass (Kaneko et al., 1983). Further, average power output was maximized at the 30% and 45% loads which is in agreement with that found for isolated bundles of fiber segments (Faulkner et al., 1986) and intact muscle groups (Wickiewicz et al., 1984) using

electrical stimulation as well as voluntary single joint movements (Kaneko et al., 1983). The findings of the current study are in close agreement with the research into the effects of load on the force, velocity and power output during vertical jump performance (Bosco and Komi, 1979; Komi, 1984) indicating that the performance of powerful movement by the upper body has similar characteristics to that of the lower body.

There were considerable differences in the force, power output, and time duration of SSC versus CO throws, but the stretch shortening cycle did not enhance performance in terms of the peak velocity, or height thrown. Although the force output was considerably higher at the start of the concentric phase in the SSC throws, there was no difference compared with the CO throws over the remaining 95% of the concentric movement. Although the average force was somewhat higher in the SSC throws, the time of the concentric phase was lower compared with the CO throws, resulting in similar impulse being applied in both conditions. As such the change in momentum over the course of the concentric movement and resulting release velocity were not significantly affected by the performance of a prior countermovement.

### ***The Effect of Load***

As expected, when projecting objects of increasing mass, the velocity of the movement decreases while the force required increases. The heavier loads cannot be moved as rapidly and so the time duration of the concentric phase increases. Even though the subjects were attempting to accelerate the bar as rapidly as possible, the peak force output which could be produced was not as high for the lighter loads due to the force-velocity relationship (Kaneko et al., 1983)(Figure 5.1). During the SSC throws, peak force was always produced at the point of the muscle's action changing from eccentric to concentric (Figure 5.4) and although the muscle was contracting isometrically at this point, and at approximately the same joint angles as for the heavier loads, equivalent force output could not be attained. Analysis of the EMG data indicated that the peak level of activity and the average over the concentric movement were reduced at the lower loads. This has also been observed for the biceps during maximal elbow flexion movements against various loads (Moritani et al., 1987), however, similar EMG activity has been observed for the squat regardless of the load (e.g. Bosco et al., 1982; Häkkinen et al., 1986). Perhaps, the present subjects, accustomed though they were to heavy resistance bench pressing, were unable to maximally recruit the motor unit pool during maximal power throws with lighter loads. It could be speculated that training over an extended period using bench pressing of heavy loads with slow movement velocities may be detrimental to light load, high velocity performance. However, this cannot be established from the current study, or previous research literature and therefore requires

further research. Also, whether such a phenomenon would be changed by specific light load, high velocity training requires further investigation.

Although the quantity of EMG activity increased with increasing load, the mean and median frequency decreased. It could be speculated that this indicates a preferential recruitment of fast twitch motor units during the lighter load throws when the subject is attempting to maximise power output (Grimby and Hannerz, 1977). When throwing the heavier loads the movement is slower, and requires greater force production with a longer duration of activation, thus a greater proportion of the motor unit pool is recruited with the use of both fast and slow twitch motor units. There is also the possibility of acute fatigue of some fast twitch subtypes during the high load contractions, which would also contribute to decreases in EMG power spectrum. The increase in the median and mean frequency of the EMG power spectrum with the decrease in load could be attributed to movement artifact (Winter, 1990). However, this is unlikely as the frequency of the fastest movement was less than 3 Hz, a high pass filter of 3 Hz was used, and high quality cabling and amplifiers such as those used in this study have been shown to minimise movement artifact (Winter, 1990). If the shifts in EMG power spectrum are attributable to differences in recruitment pattern for fast, light load, ballistic movements compared with slower, heavy load movements performed powerfully, there may be implications for the training of maximal power performance. The relative effectiveness in this regard of powerful movements performed with light versus heavy loads during training certainly requires further investigation. It should be noted, however, that changes in the power density spectrum derived from the interference EMG are not an accurate index of shifts in motor unit recruitment. Mean and median frequency are considerably influenced by the shape of the motor unit action potentials (Hermens et al., 1992) and differences in action potential shape are largely due to varying distances between the recording electrode and the active muscles (Roeleveld et al., 1997).

It should be noted that the force output and muscle activation even for the lightest loads were considerable and much greater than the mass of the load being thrown would suggest. This was a result of the high accelerations being produced and suggests a much higher overload on the neuromuscular system than would result from a traditional “bench press” lifting of the bar rather than a ballistic throw (*see* Chapter Five). This is true also for maximal power squat jumps performed with relatively light loads (Häkkinen et al., 1986)

The highest power output measured as the average over the concentric phase was produced at the 30% of 1RM load. However, this was only slightly higher and not significantly different from the power output for the 45% load. This lends further support to the hypothesis that the

optimal load for the muscle to produce maximal power output is an inherent aspect of its function. That is, due to the chemo-mechanics of the contractile machinery of muscle it appears that a load of 30% MVC or 30% of maximum shortening velocity is the point at which maximum mechanical power can be produced. Of interest was the result that peak instantaneous power output was produced at the 15% and 30% loads and decreased with increasing load thrown. Perhaps this was because a 1RM bench press was used as the criterion measure of maximal strength and the fact that the load was accelerated through a fairly large range of joint angles. The weight lifted during the 1RM test would be equal to the maximal strength at the “sticking point” combined with the additional force derived from the stretch shortening cycle (Elliott et al., 1989). Thus, the combination of joint angle and velocity of shortening may have permitted the load calculated as 15% and 30% of 1RM to maximise power at a single point in the movement.

### ***SSC Throw Versus CO Throw***

The performance of a stretch (eccentric) phase prior to the concentric push influenced both the kinetics and kinematics of the movement with average velocity, average force, peak force, average power, and peak power being higher at all loads for the SSC movement. No differences were observed between the SSC and CO throws in what could be considered the most important performance criteria, that of peak velocity attained and height thrown.

There was significantly greater EMG activity in the triceps and pectoralis major during the first 50 ms and 100 ms of the concentric phase for the SSC throws compared with the CO. Thus, although the subjects were attempting to maximally activate the muscle from the onset of the CO throws, the time duration of 100 ms was probably too short for maximum voluntary activation. Secondly, the voluntary “preactivation” during the eccentric stretch with active reflex function may have contributed favourably to the higher EMG activity recorded during the early concentric phase of the SSC throw. On examination of the changes in velocity through the concentric movement (Figure 5.3), the SSC contributes to the beginning phase of the throw, but this diminishes towards the later portion of the throw. The higher force output during the first 5% of bar movement in the SSC throw (Figure 5.5) accelerates the load more quickly initially, however, later in the movement, bar velocity increases to a point at which the force output of the SSC throw is only slightly higher or similar to that of the CO throw (Figure 5.5). This would appear to be a function of the force-velocity relationship such that the facilitation of bar velocity by the stretch shortening cycle will be gradually lost as the ability of the muscle to generate force at high velocities of shortening comes to dominate the movement. The merging of the power curves as the throw proceeds (Figure 5.7) clearly shows that although power output of the muscle is enhanced by the preceding stretch

movement, this effect is apparent primarily for the initial 50% to 80% of the total concentric movement.

As already discussed, a significant enhancement of performance through prestretching has been demonstrated for vertical jump (Bosco and Komi, 1979; Komi and Bosco, 1978; Komi, 1984) and an upper body push (Bober et al., 1980; Gollhofer et al., 1987). The most plausible explanation as to why such a result was not found as such in this experiment lies in the time duration and range of motion of the movement under investigation. For example, Bosco and Komi (1979) in examining counter movement and depth jumps recorded concentric movement times of 100-150 ms, however, even the lightest load used in this study involved an average concentric movement time of 327 ms with up to 1541 ms for the 90% 1RM load (Table 5.2). Thus the benefit of prestretching is lost if the movement continues over too long a time period or movement range. A similar effect has been reported for counter movement and squat jumps (Bosco et al., 1982) with smaller differences in performance being observed at the higher loads. Bosco et al. (1982) suggested that the long stretching phase (approx. 500 ms) results in an increased coupling time and thus stored elastic energy is lost.

This aspect requires further investigation particularly with respect to the training of such movements as the bench press and squat. As the stretch shortening cycle does not appear to contribute significantly to longer duration concentric movements, training methodologies may need to be modified to develop rather the muscle's ability to contract forcefully at fast shortening velocities and/or over shorter ranges of motion. In particular, the effectiveness of stretch shortening cycle training (plyometrics) for such activities needs to be addressed.

The influence of the prior stretch was most apparent in the velocity (Figure 5.3) and power (Figure 5.7) graphs comparing the SSC and CO throws at the heavier loads. It would appear that the potentiation of force output and subsequently greater initial velocity of bar movement is essential in carrying the bar through the "sticking region" of the bench throw movement. This can be observed for the velocity of the bar under the 90% load (Figure 5.3) where a deceleration of the bar occurs around 35%-45% of the concentric bar displacement.

The mean triceps, peak pectoralis major, and peak triceps EMG activities were higher during the SSC throw but there were no differences in mean deltoid, peak deltoid, or mean pectoralis major. Thus, the efficacy of concentric only power training requires further investigation. As mentioned above, the SSC only effected the velocity profile of the early phase of the movement and there was little difference between the peak velocity (release velocity) between the two throws. CO only movements may be useful for maintaining or increasing muscle power during

rehabilitation from injury without the risk of the high peak forces (Figure 5.4). Both peak force and the mean force over the concentric phase were significantly lower for the CO throw than the SSC throw (Figure 5.5).

### ***The Eccentric Phase***

Although the time duration of the eccentric phase of the SSC throws did not change with load the velocity and force demonstrated marked load effects. As the load increased the subjects did not allow the load to attain as high a velocity, and the peak in velocity tended to occur later in the eccentric phase for the lighter loads. However, the average and peak force exerted during the eccentric phase increased with the higher loads.

## **CONCLUSIONS**

The ballistic upper body throws studied exhibited the same velocity-force-power relationships as has been found previously. The 30% and 45% of 1RM loads resulted in the highest mechanical power output. The performance of a stretch movement prior to the concentric push altered many of the kinematic, kinetic and muscle activation characteristics but there was no significant potentiation in terms of height thrown or peak velocity. It is therefore suggested that movements involving a concentric action of long duration and/or range of movement are limited primarily by the ability of the muscle to contract forcefully at fast shortening velocities while the contribution of the stretch shortening cycle will be gradually lost during this later stage. Activities involving such movements may require consideration of this in the design of resistance training methods.

# **Chapter 6**

## **EXPERIMENT FOUR**

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### **BALLISTIC RESISTANCE TRAINING AND THE DEVELOPMENT OF VERTICAL JUMP PERFORMANCE OF ELITE ATHLETES**

#### **INTRODUCTION**

The predominant requirement in a large number of sports is maximal power production. For the lower body this is perhaps best exemplified in the vertical jump. Here the muscles about the hip, knee and ankle act rapidly and with high force to produce the greatest possible velocity of the body as it leaves the ground. The jump height produced is determined purely by this takeoff velocity.

Much research has been directed towards determining the effects of various training techniques on vertical jump (Adams et al., 1992; Clutch et al., 1983; Di Brezzo et al., 1988; Duke & BenEliyahu, 1992; Häkkinen & Komi, 1985; Holtz et al., 1988; Lyttle et al., 1996, Schmidtbleicher et al., 1988; Wilson et al., 1993). Research by Wilson et al. (1993) compared the effects of 10 weeks of training using traditional back squats, loaded jump squats, or plyometrics in the form of drop jumps, on vertical jump performance. The loaded jump squats were completed using a load, which allowed the subjects to produce the greatest mechanical power output. This has been determined in this and other studies (Kaneko et al, 1983; Moritani et al, 1987) to be around 30% of 1 RM. All the training groups produced increases in vertical jump performance excepting the plyometric group which did not increase concentric only squat jump height. The maximal power group produced the greatest increase in counter movement jump of 18% which was significantly greater than the plyometric (10%) and weight training (5%) groups. For the squat jump the

maximal power group increased 15% which was significantly greater than the plyometric (7.2%) and weight training (6.8%) groups. These results were similar to that obtained by Berger (1962) who also found that performance of jump squats with a load of 30% of maximum resulted in greater increases in vertical jump as compared with traditional weight training, plyometric training or isometric training.

The study by Wilson et al. (1993) demonstrates many of the aspects of power performance outlined previously. As has been the observation of several studies (Bosco et al., 1982; Schmidbleicher et al., 1988; Van Leemputte et al., 1983), plyometric training increases CMJ performance but not SJ height. This may be due to the plyometric training enhancing the ability of the subjects to utilize the elastic and neural benefits of the SSC but not increasing leg strength and contractile power efficiently.

The traditional weight training increased vertical jump ability but not to the same extent as the maximal power group. This may be due to an inherent problem with traditional weight training when attempting to increase power output rather than strength (*see* Chapter Five). It has been observed that the load is decelerating for a considerable proportion (24%) of the concentric movement (Elliott et al., 1989) during traditional weight lifting exercise. This percentage increases to 52% when performing the lift with a lower percentage (81%) of 1RM lifted (Elliott, et al., 1989) or when attempting to move the bar rapidly in an effort to train more specific to the movement speed of the target activity (*see* Chapter Five). Plyometric and weighted jump squat training avoids this problem by allowing the athlete to accelerate all the way through the movement (Hatfield, 1989). This form of training has been described in Chapter Two as “ballistic” resistance training. In comparing heavy weight training with lighter weight, power training most studies have found the later to be more effective (Häkkinen & Komi, 1985; Komi et al., 1982).

Several studies have compared the effectiveness of plyometric, weight training and a combination of plyometric and weight training (Adams et al., 1992; Blakey and Southard, 1987; Clutch et al., 1983; Ford et al., 1983; Lyttle et al., 1996; Polhemus et al., 1980). Although specific training protocols vary, in general, plyometrics have been shown to be effective for increasing vertical jump (Adams et al., 1992; Clutch et al., 1983; Di Brezzo et al., 1988; Duke & BenEliyahu, 1992; Holtz et al., 1988; Schmidbleicher et al., 1988; Wilson et al., 1993). Traditional weight training has resulted in increases in vertical jump by the majority of the research (Adams et al., 1992; Bauer et al., 1990; O’Shea & O’Shea, 1989; Williams, 1991; Wilson et al., 1993; Young & Bilby, 1993) with a limited number of papers finding no change in already strength trained subjects (Häkkinen & Komi, 1985; Komi, et al., 1982).

When weight training is combined with plyometrics vertical jump is increased (Bauer et al., 1990; Blakey & Southard, 1987; Clutch et al., 1983; Lyttle et al., 1996) and this can be a greater stimulus to vertical jump performance than either weights or plyometrics training alone (Adams et al., 1992). These findings highlight the multi-faceted nature of vertical jump performance with a mixed methods approach being most effective as it develops more components of the vertical jump (*see* Chapter Two).

Ballistic resistance training has been difficult to implement because of the high impact forces imparted to the athlete's body on landing from a jump (*see* Chapter Four). However, it has been shown in Chapter Four that electro-mechanical devices can be used to reduce the downwards force of the load and so control the eccentric loading on the athlete during the jump.

Although research has demonstrated the efficacy of ballistic resistance training (Wilson et al., 1993; Lyttle et al., 1996) the subjects used in these studies were not at the elite level. It remains to be determined if highly trained jump athletes will respond to a ballistic resistance training program. Also, the influence of reducing the eccentric loading on the neuromuscular adaptations and the resulting changes in vertical jump performance requires investigation. In addition, should significant changes in functional jump performance result, what characteristics of muscle function i.e. maximal strength, SSC capability, mRFD, and power output have exhibited adaptations which produce this performance improvement. Therefore, the aim of this study was to determine the effects of an 8 week ballistic resistance training program on vertical jump performance of elite volleyball players.

## **METHODS**

### ***Subjects***

Sixteen male volleyball players from a NCAA Division I team were informed of the benefits and risks of the study. Subsequently each signed an informed consent document in accordance with the guidelines of the University's Institutional Review Board for use of human subjects (Appendix F). The subjects were medically screened and had no medical or orthopedic problems which would compromise their participation and performance in the study (Appendix H). The subjects were randomly allocated to either the treatment or control with 8 subjects in each group. Subject characteristics were as follows: age,  $19\pm 2$  yrs; height,  $189\pm 7$  cm; weight,  $84\pm 6$  kg. The treatment and control groups were compared for height, weight, and pre-training jump and reach performance using one-way ANOVA to ensure there were no statistical differences between the two groups prior to commencement of the training intervention.

## ***Experimental Design and Procedures***

This study was a longitudinal training experiment with pre and post training testing.

### **Training Program**

All subjects completed the same resistance training program for the upper body, however, the control group completed squat, leg press, leg curl and leg extension exercises while the treatment group completed ballistic resistance training consisting of jump squats with a counter movement performed on a Plyometric Power System (PPS) (Norsearch, Lismore, Australia). The complete training programme for both groups is provided in Table 6.1. For each exercise the load was set so as to result in failure to complete any more repetitions than specified for that exercise. In other words, the sets were to failure using loads of the repetition maximum for that exercise. If more than the specified number of repetitions were completed then the load was increased for the subsequent training session. Training volume was equalised between the two groups based on total number of repetitions completed. The ballistic training program consisted of 6 sets of 6 repetitions performed with 2 sets at each load of 30%, 60% and 80% of the subject's pre-test 1RM squat. The eccentric brake system previously described in Chapter 4 was used to remove approximately 75% of the weight of the bar on the downwards or eccentric phase. All subjects trained for 8 weeks, two sessions per week with training logs recorded for all subjects to ensure compliance. The test measurements were taken immediately before and again after the training period.

**Table 6.1** Resistance training program for control and treatment groups. The treatment group completed the same program except the squat and leg press exercises were substituted with jump squats.

CONTROL GROUP				TREATMENT GROUP		
	Exercise	sets	reps	Exercise	sets	reps
DAY 1	bench press	2	10			
	incline press	1	10			
	seated press	2	10			
	side lat raise	2	10			
	chest flies	2	10			
	front raise	1	10			
	tricep pushdown	2	10			
	tricep kickbacks	1	10			
	shoulder shrugs	1	10			
	rotator cuff	1	15			
	weighted crunches	2	15			
DAY 2	squat	3	6	Squat Jumps	3	6
	leg press	3	6	Squat Jumps	3	6
	leg curl	2	10			
	leg extensions	1	10			
	calf raise	1	15			
	seated row	2	10			
	lat pulldown	2	10			
	dumbbell row	1	10			
	standing arm curl	2	10			
	preacher curl	1	10			
	shoulder adduction	1	15			
	low back extensions	1	15			
	DAY 3	seated press	2	10		
side lat raise		1	10			
bench press		2	10			
dips		2	10			
upright row		2	10			
incline flies		1	10			
tricep extension		2	10			
tricep kickback		1	10			
shoulder shrugs		1	10			
rotator cuff		1	15			
lying reverse crunch		2	15			
DAY 4	squat	3	6	Squat Jumps	3	6
	leg press	3	6	Squat Jumps	3	6
	leg curl	2	10			
	leg extension	1	10			
	standing calf raise	1	15			
	lat pulldown	2	10			
	seated row	2	10			
	chin-ups	1	10			
	standing arm curl	2	10			
	reverse curl	1	10			
	shoulder adduction	1	15			
	low back extensions	1	15			
	trunk twists	2	15			

## Testing Protocols

*Jump and Reach Tests:* Jump and reach performance was measured using a Vertec (Questtek Corp., Northridge, CA). Reach height was established by having the subject stand flat-footed and reach up to displace the marker on the Vertec. The subject then performed two types of jumps. a) for the standing vertical jump (SJR) the subject dipped to a self-selected depth and then jumped and reached with his preferred hand to displace the marker on the Vertec; b) the subject was permitted a three step approach (AJR) followed by a takeoff from one leg to reach and displace the marker on the Vertec. Three trials were permitted for all jumps with the highest jump being used in subsequent statistical analysis.

*Maximal Squat Strength Test:* Maximal squat strength (1RM) was assessed by having the subjects perform a concentric only squat from a position of 110 degrees knee flexion using the Plyometric Power System (PPS) following methods similar to that described by Wilson et al. (1993). The load lifted in the best successful attempt was recorded in kilograms.

*Plyometric Power System Squat Jump Tests (PSJ):* Squat jump performance under loads of 30%, 60% and 90% of 1RM was assessed using the PPS. Subjects were placed in a position of 110 degrees knee flexion with the heels directly under the bar of the PPS. They were then instructed to push upwards attempting to jump for maximal height. Bar displacement and mass was recorded and various velocity, acceleration, work and power variables were calculated.

*Force Plate Tests:* Force plate testing consisted of depth jumps (DJ), counter movement jumps (CMJ), and squat jumps (SJ) with both takeoff and landing performed on a triaxial force plate (AMTI, MA). The vertical ground reaction force was recorded and measures of flight time, contact time, force, rate of force development, velocity, and power output calculated. All jumps were performed with the hands placed on the hips throughout the movement. The various jump types were used to assess specific aspects of vertical jump performance.

a) Depth Jumps: The subject dropped from a 30cm height, landed on the force plate, and then attempted to jump for maximum height, landing back on the force plate.

b) Counter movement jumps were performed by dipping down to a knee angle of 110 degrees and immediately jumping for maximum height to land back on the force plate. The subject was initially placed in a squat position such that the knee angle was 110 degrees so that they knew approximately how deep they should dip. All trials were visually checked to ensure that this depth was achieved during the counter movement jumps. The counter movement jump was performed with body weight alone.

c) Squat jumps involved the subject flexing the knees and hips such that the angle at the

knee was 110 degrees and holding this position for 4 seconds. They then jumped vertically upwards from this position attempting to attain a maximum height. If a preparatory dip was observed on the force time graph then the trial was discarded and the subject made a further attempt. Squat jumps were performed with body weight alone, and with the addition of 20 kg and 40 kg strapped to the subject's torso.

Two trials were recorded for each condition with the trial resulting in the greatest jump height used in further statistical analysis. The vertical force output was integrated with time to produce velocity and displacement data for the subject center of gravity. Summary kinetic and kinematic data were then calculated using methods described by Winter (1990).

As a number of novel tests and calculated variables were used in this study, the test-retest reliability was determined for all variables by comparing two trials from the pretraining testing sessions. The intraclass correlation coefficient (ICC), technical error of measurement (TEM), and technical error of measurement as a percentage of the mean measurement (TEM%) was calculated according to the methods of Knapp (1992) for each variable. The results of this analysis appear in Table 6.2.

### ***Statistical Analysis***

Means and standard deviations were calculated. Multivariate ANOVA was performed with two independent variables of group (control and treatment) and test occasion (pre and post training period). In the event of a significant interaction univariate F-tests were applied to each dependent variable followed by Newman-Keuls post-hoc analysis. A criterion alpha level of  $p \leq 0.05$  was used to determine statistical significance. Statistical power for comparisons of both the pre-post effects as well as pre-post by group effects were calculated for all measured variables. The results of this analysis are presented in Table 6.3.

**Table 6.2** Measurement reliability of all variables used in the Jump and Reach, Force Plate, and Plyometric Power System testing.

<b>Variable</b>	<b>ICC</b>	<b>TEM</b>	<b>TEM%</b>
<b>Jump and Reach Tests</b>			
standing vertical jump (cm)	0.978	3.81	5.83
3 step vertical jump (cm)	0.972	4.44	5.81
<b>Force Plate Tests</b>			
flight time (secs)	0.953	0.00445	0.79
flight to contact ratio	0.999	0.00033	0.02
landing impact (N.s)	0.774	5.58	7.50
jump impulse (N.s)	0.954	7.22	1.63
jump height calculated from flight time (m)	0.947	0.00817	2.21
maximum displacement (m)	0.678	0.0535	6.47
maximum velocity (m.s <sup>-1</sup> )	0.951	0.0283	1.00
mean force (N)	0.999	1.67	0.12
mean power (W)	0.796	90.7	4.97
peak force (N)	0.927	30.5	1.53
peak power (W)	0.998	16.0	0.34
mRFD (N.s <sup>-1</sup> )	0.403	1380	19.6
<b>PPS Squat Jump Tests</b>			
maximum acceleration (m.s <sup>-2</sup> )	0.998	0.0205	0.29
maximum displacement (m)	0.918	0.0116	1.63
maximum force (N)	0.963	14.1	1.98
maximal power (W)	0.690	83.6	6.68
maximum velocity (m.s <sup>-1</sup> )	0.775	0.0388	1.88
mean force (N)	0.991	5.28	1.00
mean power (W)	0.998	2.38	0.48

**Table 6.3** Statistical power for comparisons of both the pre-post effects as well as pre-post by group effects calculated for all measured variables.

Variable	Pre-Post	Pre-Post by Group
<b>1RM Squat Test</b>	7.0%	5.9%
<b>Jump and Reach Tests</b>		
standing vertical jump	99%	60%
3 step vertical jump	88%	65%
<b>Force Plate Tests</b>		
flight time	87%	42%
contact time	94%	89%
flight to contact ratio	74%	79%
jump impulse (N.s)	6.3%	5.0%
jump height calculated from flight time (m)	6.9%	5.1%
maximum displacement (m)	13%	5.3%
maximum velocity (m.s <sup>-1</sup> )	16%	28%
mean force (N)	99%	90%
mean power (W)	92%	18%
peak force (N)	88%	80%
peak power (W)	63%	9.6%
mRFD (N.s <sup>-1</sup> )	99%	97%
<b>PPS Squat Jump Tests</b>		
maximum acceleration	92%	5.1%
maximum displacement	99%	50%
maximum force	92%	11%
mean force	84%	16%
maximal power	99%	83%
mean power	74%	12%
maximum velocity	99%	81%

## DELIMITATIONS

The samples chosen for this study were limited to adult males who were elite volleyball players.

Only the standing and approach jump and reach tests were used to assess on-court performance improvements.

## LIMITATIONS

In addition to limitations arising from the above:

Sample size was limited to sixteen subjects due to the difficulty in recruiting athletes at the elite level.

The athletes completed a considerable amount of additional conditioning and skills training during the ballistic resistance training intervention period which may have interfered with the development of maximum muscle power (*see Kraemer et al., 1995*). This situation was unavoidable due to the strict training programme which athletes at this level were required to complete.

Musculo-tendinous stiffness and muscle activation was not measured due to the limited time which athletes at this level would make available for testing. Both of these measurements are relatively time consuming.

A stretch shortening cycle movement was not used for the determination of 1RM or performance of the jump squats measured by the Plyometric Power System because of instructions from the head coach that these lifts were to be avoided.

The training intervention was limited to eight weeks to coincide with the team's pre-season preparation.

A direct comparison of braked versus non-braked ballistic resistance training could not be completed due to the inability of the subjects to complete the jump squat exercises without a reduced eccentric load.

The PPS restricts movement to the vertical plane. However, traditional resistance training and athletic movements are not restricted in this manner. Training on the PPS is therefore not specific to athletic performance such as vertical jump in this regard. This may have influenced the training adaptations resulting from the PPS squat jump programme.

## RESULTS

### ***Jump and Reach Tests***

The results of the standing and approach jump and reach tests are presented in Table 6.4. The control group's performance did not change over the training period for either jump. The treatment group increased jump height significantly over the training period by  $5.9\pm 3.1\%$  and  $6.3\pm 5.1\%$  for the standing and approach jump respectively. Both of these percentage increases were significantly greater than for the control group.

**Table 6.4** Pre and Post test results for standing and 3-step approach jump and reach tests for control and treatment groups.

Jump Type	Group	Pre-Test (cm)	Post-Test (cm)	Change (%)	Effect Size	p value
Standing	Control (n=8)	68.1±7.0	69.4±7.4	1.3±2.5	0.235	0.186
	Treatment (n=8)	67.6±4.1	71.5±4.6	5.9±3.1	0.805	0.001
	p value	0.847	0.499	0.039		
3-Step	Control (n=8)	80.4±6.2	80.5±7.4	0.18±4.7	0.002	0.908
	Treatment (n=8)	78.0±6.2	83.0±7.2	6.3±5.1	0.656	0.008
	p value	0.468	0.513	0.024		

### ***Maximal Squat Strength***

There were no significant changes in 1RM squat strength in either group between the pre and post training tests (Table 6.5).

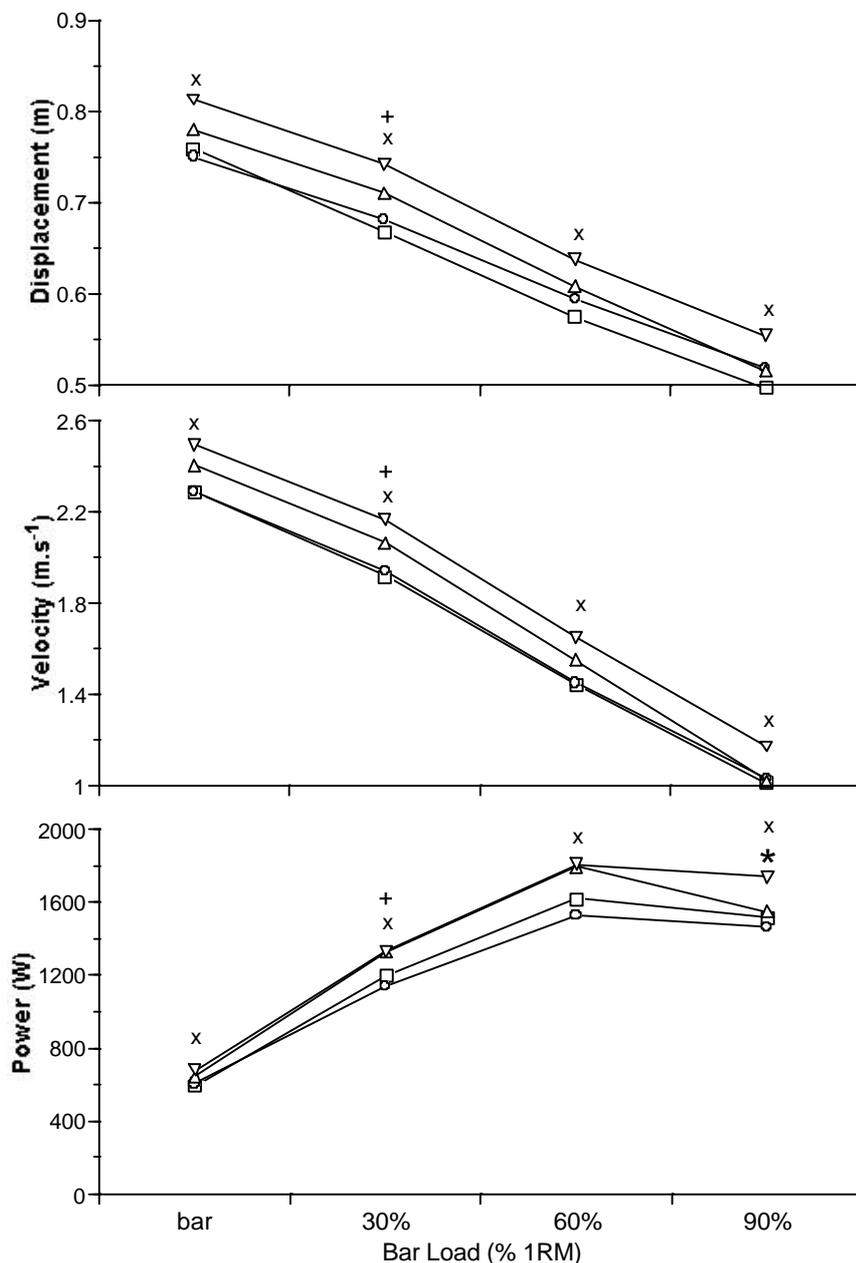
**Table 6.5** Pre and Post test results for 1RM squat for control and treatment groups.

Group	Pre-Test (cm)	Post-Test (cm)	Change (%)	Effect Size	p value
Control (n=8)	145.8±18.5	146.7±23.2	1.0±10.8	0.008	0.832
Treatment (n=8)	137.9±18.8	139.13±23.4	1.0±10.9	0.007	0.830
p value	0.409	0.540	0.998		

### ***Plyopower Squat Jump Tests***

MANOVA revealed significant group by prepost by load and group by prepost interactions. Subsequent F-tests showed significant group by prepost effects for bar displacement, velocity, and power. Figure 6.1 compares the two groups pre and post training. Specifically, the treatment group increased bar displacement, velocity, and power output over the training period at all the loads

tested. The control group produced increases in displacement, velocity and power output only at the 30% of 1RM load. No other significant changes were recorded for the control group. A comparison of the percentage changes over the training period revealed that only power output at the 90% of 1RM load was increased significantly more for the treatment compared with control groups.



**Figure 6.1** Mean data for the treatment group pre (**â**) and post (**ä**) test and the control group pre (**G**) and post (**B**) test for concentric only jump squats performed on the Plyometric Power System with loads of bar weight, 30%, 60% and 90% of each subject's previously determined 1RM concentric only squat. Displacement was measured as the total bar movement. Velocity and power were determined as the peak produced during the jump. (x indicates significant difference pre to post for the treatment group; + indicates significant difference pre to post for the control group; \* indicates significant difference between groups for percentage change pre to post:  $p \leq 0.05$ ).

## **Force Plate Tests**

### **Counter Movement Jump Tests**

There were no significant interactions of group or test occasion for any of the variables measured during the counter movement jump test. Jump height calculated from flight time was 1.9% and 3.0% higher pre to post training for the control and treatment groups respectively. However, the statistical power of the pre-post comparisons was only 0.09 and 0.12 for the control and treatment groups respectively and as such the changes were not statistically significant at the  $p \leq 0.05$  probability level. The control group significantly increased maximum velocity by  $5.2 \pm 4.2\%$ . The treatment group significantly increased mean force by  $2.1 \pm 2.5\%$  and peak power by  $8.0 \pm 8.9\%$ . There were no significant differences between the groups for percentage change pre to post testing for any of the measured variables.

### **Squat Jumps**

There were significant group by prepost interactions for the variables measured during the squat jump tests on the forceplate. Figures 6.2-6.4 contain the results of these tests. Notably, between the pre and post tests the treatment group produced significant increases in peak force production of 11.3%, 5.4%, and 5.4% when performing squat jumps with BW, BW+20kg, and BW+40kg respectively (Figure 6.2). The control group only increased peak force at the highest load of BW+40kg by 2.5%. The 11.3% increase by the treatment group when jumping with BW only was significantly greater than the percentage change by the control group. When examining the average force produced over the concentric phase of the squat jump the treatment group exhibited 9.7% and 4.7% increases for the BW and BW+40kg trials. The control group did not produce any change in average force over the training period. In addition, the percentage increase in force was significantly greater for the treatment group than the control group for the BW only trial.

Peak power output was not significantly changed pre to post testing for the treatment group (Figure 6.3), however, a trend towards increases can be seen across all the loads tested. Variability for this measure was quite high and thus statistical significance was not achieved. The control group did produce a significant increase in peak power output of 7.7% for the BW+40kg load, however, this was not significantly different from the percentage change for the treatment group. The only significant change in the average power produced during the concentric phase of the squat jumps was exhibited by the treatment group for the BW only trial (18.9%), however, this was not significantly different from the percentage change for the control group.

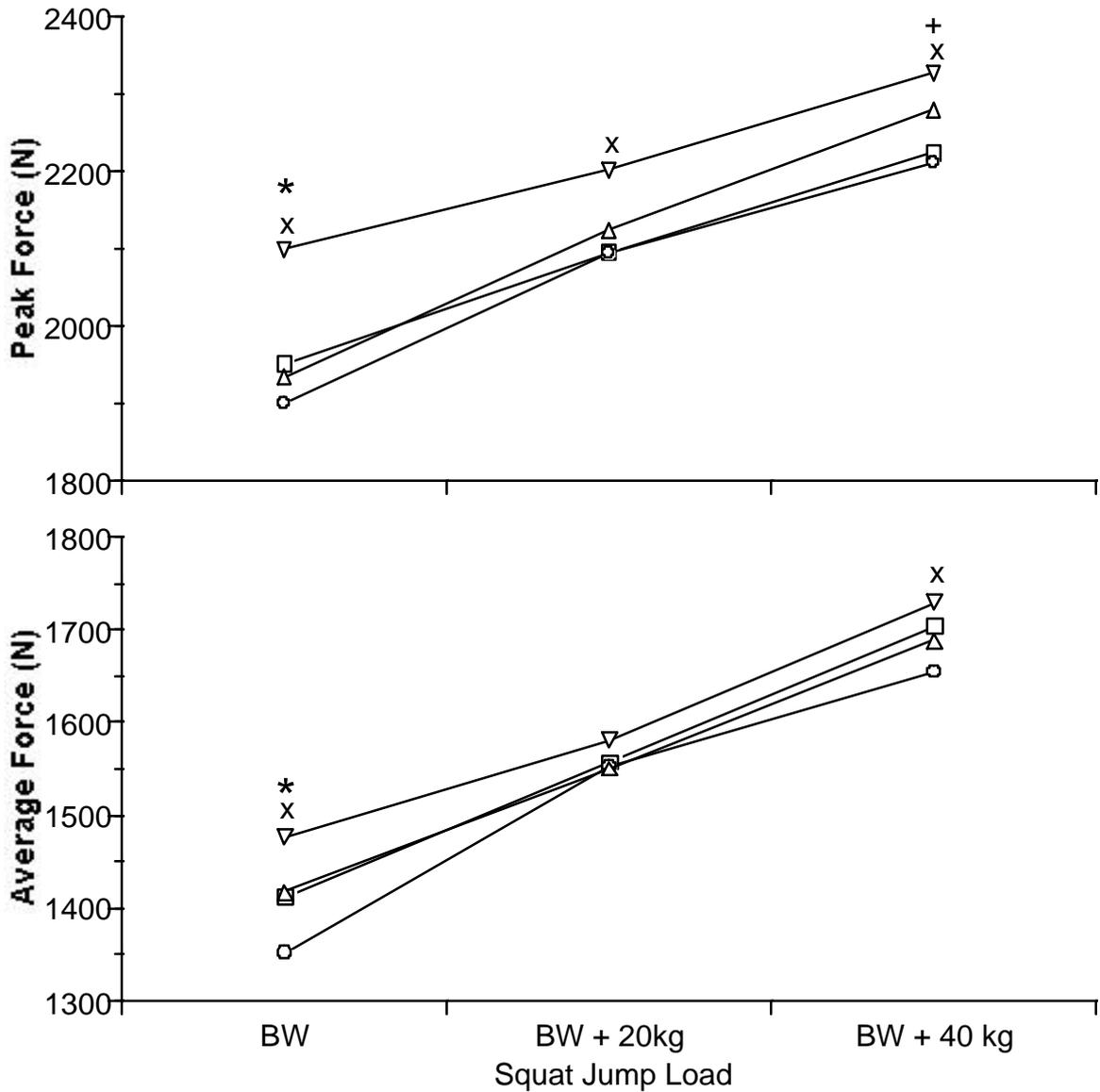
The treatment group produced a 47% increase in mRFD over the course of the training period and this was significantly greater than the control group which did not change mRFD pre to post testing. The control group did, however, produce a significant increase in mRFD (9.2%) for the BW+20kg load but this was not significantly different to the treatment group.

### **Depth Jumps**

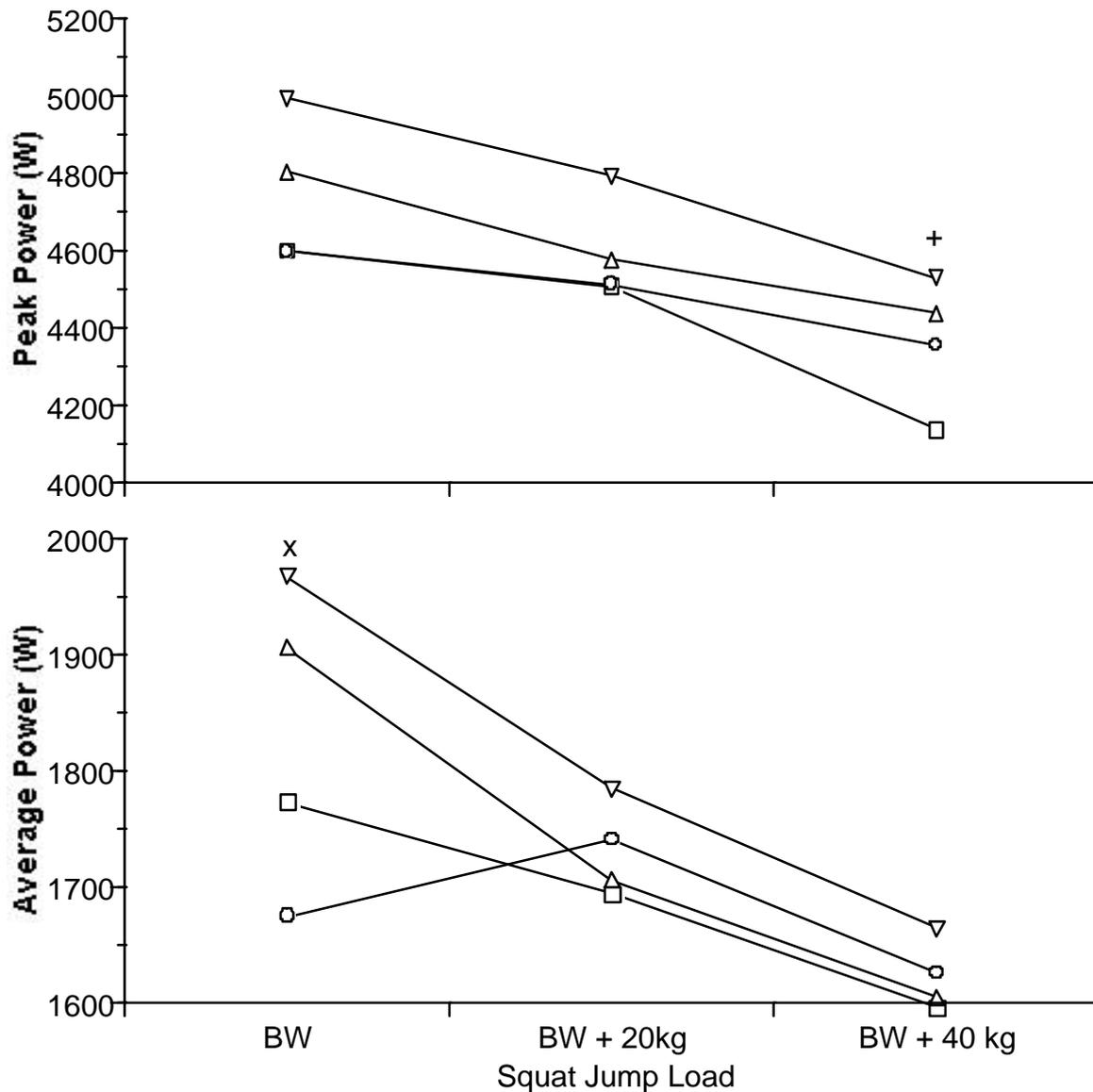
The results for the depth jump tests appear in Table 6.6. There were no significant differences between the control and treatment groups for any of the measured variables either before or after the training period. The treatment group significantly decreased contact time by  $14.6\pm 9.7\%$  and this was significantly greater than the control group which had no change. Flight time increased by  $4.7\pm 3.4\%$  for the treatment group and  $1.9\pm 2.2\%$  for the control group, however, there was no significant difference between the groups for the percentage change. The treatment group increased their flight to contact ratio by  $24.4\pm 19.6\%$  and this was significantly greater than the control group which did not change over the training period.

**Table 6.6** Pre and post test results for depth jumps from a 0.3 m height for the control and treatment groups.

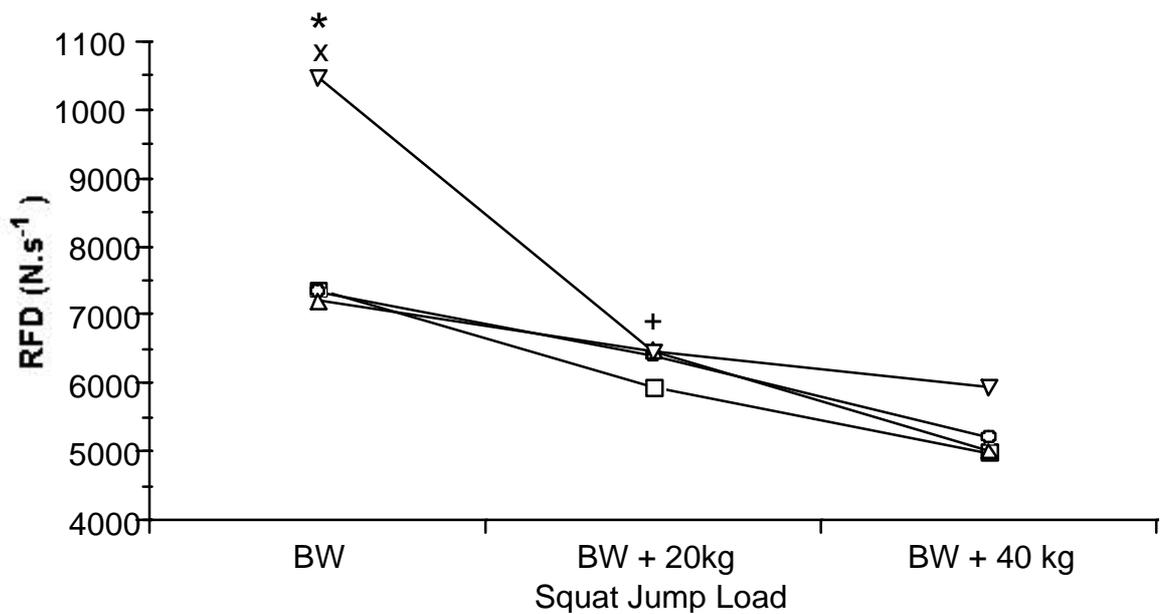
Variable	Group	Pre-Test	Post-Test	Change (%)	Effect Size	p value
Contact time (secs)	Control	0.56±0.07	0.59±0.07	6.3±14	0.151	0.301
	Treatment	0.64±0.09	0.54±0.10	-14.6±9.7	0.748	0.006
	p value	0.09	0.32	0.006		
Flight time (secs)	Control	0.58±0.03	0.59±0.04	1.9±2.2	0.460	0.045
	Treatment	0.57±0.02	0.60±0.02	4.7±3.4	0.697	0.010
	p value	0.68	0.55	0.07		
Flight to contact ratio	Control	1.05±0.18	1.01±0.13	-2.5±14.2	0.076	0.47
	Treatment	0.91±0.10	1.14±0.24	24.4±19.6	0.621	0.02
	p value	0.09	0.21	0.009		



**Figure 6.2** Mean data for the treatment group pre (**A**) and post (**C**) test and the control group pre (**G**) and post (**B**) test for concentric only squat jumps performed on a forceplate with loads of body weight (BW), BW+20kg, and BW+40kg. Peak force was measured as the highest ground reaction force and average force was measured as the mean ground reaction force during the concentric phase of the jump. (x indicates significant difference pre to post for the treatment group; + indicates significant difference pre to post for the control group; \* indicates significant difference between groups for percentage change pre to post:  $p \leq 0.05$ ).



**Figure 6.3** Mean data for the treatment group pre (**A**) and post (**C**) test and the control group pre (**G**) and post (**B**) test for concentric only squat jumps performed on a forceplate with loads of body weight (BW), BW+20kg, and BW+40kg. Peak power was measured as the highest power output and average power was measured as the mean power output during the concentric phase of the jump. (x indicates significant difference pre to post for the treatment group; + indicates significant difference pre to post for the control group:  $p \leq 0.05$ ).



**Figure 6.4** Mean data for the treatment group pre (**A**) and post (**C**) test and the control group pre (**G**) and post (**B**) test for concentric only squat jumps performed on a forceplate with loads of body weight (BW), BW+20kg, and BW+40kg. Rate of force development (mRFD) was measured as the greatest increase in ground reaction force for a given 50ms period during the concentric phase of the jump. (x indicates significant difference pre to post for the treatment group; + indicates significant difference pre to post for the control group; \* indicates significant difference between groups for percentage change pre to post:  $p \leq 0.05$ ).

## DISCUSSION

The primary results of this study indicate that an 8 week programme of ballistic resistance training is effective for increasing the jump and reach performance of elite jump athletes. These performance gains were associated with improvements in muscle force and power output, and rate of force development. Interestingly, jump height as measured by flight time did not change over the training period for either CMJ or SJ performed on a forceplate.

Ballistic resistance training has been shown to be effective for increasing maximal power performance of resistance trained though non-elite subjects (Wilson et al., 1993; Lyttle et al., 1996). The findings of the present study are that such training will also result in performance improvements in elite volleyball players who could be considered to be already close to their genetic potential in terms of vertical jump performance. These subjects had a considerable training history in terms of traditional resistance training, plyometric training, and on court drills, however, the addition of ballistic training for an eight week period resulted in a 5.9% and 6.3% improvement

in standing and approach jump and reach height respectively. This would certainly be considered meaningful as well as statistically significant given the level at which these athletes are competing. The results are comparable with those of Lyttle et al. (1996) who found 7.9% and 5.8% increases in performance of similar jump tests following 8 weeks of ballistic resistance training in non-elite athletes. Fry et al. (1991) has also reported a 7.4% improvement in approach jump and reach performance by women collegiate volleyball players following a training programme combining traditional weight training and plyometrics.

The control group completed traditional, slow velocity resistance training as well as on-court practice involving a large volume of jumping over the same period and it is notable that their vertical jump performance did not change. Lyttle et al. (1996) found a combination of heavy resistance training and plyometrics to be equally effective as ballistic resistance training. Perhaps because the population used had never completed any maximal power type training, both protocols were effective because each represented a novel stimulus to the neuromuscular system. Komi and Häkkinen (1988) have reported that in relatively untrained subjects a wide range of interventions will produce adaptations. The subjects used in the current study were familiar with both strength training and the on-court volleyball pre-season preparation and so little if any improvements resulted. However, the addition of the ballistic resistance training was a novel stimulus, which was very specific to vertical jumping, and resulted in performance improvement.

The increase in jump and reach performance by the treatment group is the most relevant even though changes in some of the forceplate tests did not realise significant increases. In terms of on court performance, the jump and reach test is the most specific and as such the standard by which improvement should be gauged. The other tests were performed in an attempt to explain or identify specific adaptations in jumping performance which contributed to the overall increase in jump height.

Given the specificity of the ballistic resistance training to the squat jump tests on the PPS it is not unexpected that the treatment group produced increases in jump height, velocity and power output over the full spectrum of loads tested. It could be hypothesised that the heavy resistance training by the control group would result in improvements in performance for the heavier (90% 1RM) load but this was not apparent. Neither group increased 1RM strength for the concentric only test and this may further support the test specificity of strength and power measures (Murphy et al., 1994). Training logs of the loads used in the leg press and squat exercises by the control group were not reviewed, however, based on previous research (Häkkinen and Komi, 1985a; Wilson et al., 1993) it would be expected that strength would have increased for these exercises. No such increase was apparent in the 1RM squat strength and 90% 1RM jump squat tests used in this study.

Further, although the treatment group was training with loads up to 80% of 1RM, their 1RM strength was not improved. This may have been the result of using a concentric only 1RM test while all ballistic resistance training was performed using SSC movements. Alternatively, the neuromuscular adaptations resulting from ballistic resistance training even with heavy loads may be different from that resulting from traditional slow velocity resistance training. As such, no improvement in 1RM strength was realised. Previous research has found load and velocity specific training effects (Kaneko et al., 1983) following training using ballistic movements and so it is reasonable to assume that no gains in slow velocity maximum strength would result from the ballistic training programme used in this study.

The lack of any change in 1RM strength by either group was certainly unexpected and the following points are offered as possible explanations:

All subjects had a minimum of 12 months prior weight training experience and so the program may have had little additional effect on their strength levels.

The resistance training programme as completed by all subjects incorporated no variations in repetitions or intensity and so may not have been optimal for strength gains in these athletes.

The team was undergoing a high volume of on-court skills and cardiovascular endurance training during the resistance training period. This may have interfered with the development of maximal strength (Kraemer et al., 1995).

### ***Possible factors contributing to the increased performance***

The 1RM test results indicate that the strength of the subjects did not change over the training period and therefore this is unlikely to have contributed to the improved jump and reach results. However, jump height, peak movement velocity, and peak power output increased for all loads during the squat jumps performed on the PPS (Figure 6.1). It is possible then that although strength at slow velocities was not improved, the ability of the neuromuscular system to maintain tension while the muscles are rapidly shortening (fast velocity strength) may have been enhanced. This hypothesis is supported to some extent by the relatively large increases in average force and power output during the light load (BW only) squat jumps performed on the forceplate.

Perhaps the most significant adaptation was in terms of mRFD which increased some 47% (Figure 6.4) for the treatment group performing a squat jump on the forceplate. This was a dynamic measure of mRFD, which has been reported by Murphy et al. (1994) as being closely related to maximal power performance. This is an interesting finding which is strongly supported in previous research by Häkkinen et al. (1985) who found that maximal power type resistance training resulted

in significantly greater increases in mRFD than heavy resistance training and this was related to greater improvements in vertical jump performance.

The evidence as to the relative importance of improvements in SSC performance is contradictory. The depth jump test (Table 6.6) emphasises the SSC and its influence on jump performance. In this study, the treatment group produced a 4.7% improvement in flight during the depth jump test. In addition, they significantly reduced their contact time (-14.6%) resulting in a markedly increased (24.4%) flight to contact ratio. This would appear to suggest an improvement in SSC performance, however, this cannot be adequately confirmed other than to say that the trained subjects appeared to be able to tolerate a larger stretch load, spend less time in contact with the ground, and produce a better subsequent jump height. Such performance changes have been reported to be due to improved SSC capability (Bosco, 1992a; Bosco, 1992b)

The other test that involved a SSC movement was the CMJ test. Although there were 1.9% and 3.0% increases in jump height pre to post training produced by the control and treatment groups respectively, neither change was statistically significant for this test. This would seem to indicate SSC performance was not improved markedly by the training and combined with considerable variance in the percentage change resulted in a failure to achieve a statistically significant result. Also, it is possible that the stretch load involved in a CMJ is much less than that used in the training and there may be load specific adaptations in terms of SSC as there are for muscle strength (Kaneko et al., 1983). The fact that DJ performance was enhanced by the higher resistance ballistic training supports this contention. Further research is required to determine if the amount of eccentric loading during training results in load specific SSC enhancement.

Previous research by Wilson et al. (1993) has found highly SSC load specific training adaptations. Plyometric training involves a considerable SSC component and resulted in a 10% increase in CMJ performance but only a 7.2% in SJ performance. In the same study, a weight trained group produced improvement in SJ performance of 6.8% and improved CMJ ability by only 5%. These effects presumably reflect contraction-type specific training adaptations.

Recently, Lytle et al. (1996) found the combination of plyometric and weight training to be relatively superior to ballistic resistance training for increasing SSC performance. However, the load used in this training study was limited to 30% 1RM and no eccentric braking was used so comparison with the results of the current study is difficult. Given the findings of prior research (Bosco et al., 1982; Schmidbleicher et al., 1988) the use of the eccentric braking in the current study may also have reduced the SSC training adaptations. Future research should address the specificity of concentric only and SSC movements used in training and subsequent improvements in

powerful concentric only and SSC performance.

Although power, force output and mRFD during the SJ tests on the forceplate increased over the training period in the group undertaking ballistic resistance training, the time of flight remained statistically unchanged. This seems contradictory as flight time should be a direct indicator of jump height (Bosco, 1992a; Bosco, 1992b). However, the current study has found considerable variance in flight time, particularly the changes pre to post training, and as such the statistical power of any comparisons has been very low. Although the measurement of ground reaction force revealed many interesting aspects of the jump performance, overall they did not reflect training improvements as well as the jump and reach tests. This may have been a result of the restriction of technique in the forceplate tests. The increases in neuromuscular performance resulting from the training may be better realised in a familiar skill like jump and reach rather than the hands on hip, prescribed depth, and limited trunk flexion required of the CMJ, SJ, and DJ as used in this study.

Although this study has increased our knowledge of the effects of ballistic resistance training for elite athletes there remains a number of avenues for further research. A range of loads were used in this study spanning the concentric force capability of the neuromuscular system, however, the specific adaptations resulting from training ballistically with heavy versus light loads requires investigation. Kaneko et al. (1983) has reported very load specific adaptations, however, a later paper by Behm and Sale (1993a) has stated that it is the “intention to move rapidly” which determines the training adaptations. The load and velocity specific changes occurring in terms of neural activation and motor unit recruitment patterns, as well as histochemical changes such as calcium activity and myosin heavy chain isoform profile should be examined.

Sets of 6 repetitions were completed by the treatment group, however, all the jump tests involved single jumps. Greater increases in jump performance may have been produced if sets of only 1-3 repetitions had been used in the training intervention. The optimal number of repetitions per set for developing vertical jump is not known and requires further research.

Periodisation is an area of controversy in the strength and conditioning field (Baker, 1994). The current study did not use a periodised programme and there is a need in exercise science for more work in this area. A related issue is the effect of the other conditioning and on-court practice which was undertaken during the training period. Kraemer et al., (1995) has demonstrated considerable interference of aerobic conditioning with strength development so it is reasonable to expect that the full benefit of the ballistic resistance training in this study may have been compromised.

A considerable amount of braking was used during the downward phase of the ballistic

training. Despite this, considerable performance improvements were realised and this may indicate that characteristics of the concentric phase of powerful movements dominate. For example, factors such as maximum force and the ability to maintain force output while the muscle is shortening rapidly have the greatest influence on the overall performance (*see* Chapter Six). The role of eccentric loading on maximal power development does require further investigation by a specific comparison of eccentric braking with no braking in terms of training response. It should be noted, however, that the athletes used in the current study reported that they could not tolerate the training without the eccentric braking particularly when jumping with the heavier loads. Perhaps the inclusion of plyometrics in the training programme would result in even greater SSC performance improvements as has been found combining weights and plyometric training (Lyttle et al., 1996).

## CONCLUSIONS

Ballistic resistance training is effective for increasing the vertical jump performance of elite jump athletes. The improvements result primarily from an increased ability to produce force throughout the concentric phase, an increased maximum rate of force development, and possibly improved SSC capability. The use of an electric brake to reduce the load on the downwards phase did not appear to limit these performance gains.

# **Chapter 7**

## **EXPERIMENT FIVE**

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### **RESISTANCE TRAINING INDUCED CHANGES IN MAXIMAL MUSCLE POWER IN YOUNG AND OLD MEN**

#### **INTRODUCTION**

Human muscle is composed of two broad categories of muscle cells or fibers (Green, 1986). The slow twitch fiber is characterised by high endurance, but slow rate of force production and low power output. In contrast, the fast twitch fibers possess low endurance, but a fast rate of force production and high power output (Faulkner et al., 1986). Slow twitch fibers are innervated regularly by normal daily activity; however, the fast twitch fibers are used only during muscle contractions requiring high force or rapid movement (Green, 1986).

With aging, muscle atrophy results from a gradual process of fiber denervation with loss of some fibers and atrophy of others (Aniansson et al., 1983; Faulkner and Brooks, 1995; Larsson et al., 1978; Lexell et al., 1988). Fast fibers show more denervation and atrophy than slow fibers (Faulkner and Brooks, 1995) and this atrophy, particularly of the fast twitch fibers, is most likely due to a combination of the effects of aging and physical activity levels which have declined to a chronically low intensity (Evans and Campbell, 1993; Lexell and Downham, 1992). The age-related muscle atrophy is associated with considerable decreases in muscle strength and power especially at the onset of the sixth decade both in men and women (Frontera et al., 1991; Häkkinen and Häkkinen 1991; Häkkinen et al., 1995, 1996). It has also been reported that age-related decreases in maximal power production take place actually to a greater degree than that of maximal muscle strength (Bosco and Komi 1980; Häkkinen and Häkkinen, 1991; Häkkinen et al.,

1995,1996). For example, Metter et al., (1997) report that muscle power declines at a 10% faster rate than strength in aging men. Further, Skelton et al. (1994) have shown that isometric strength declines 1-2% per annum but muscle power approximately 3.5% per annum in men over 65 years old. Faulkner et al. (1986) have demonstrated that the force per cross sectional area of Type I and Type II muscle fibers is similar, however, the peak power output of Type II fibers is fourfold that of Type I fibers. Interestingly, more recent work (Harridge et al., 1996; Harridge et al., 1998; Larsson, et al., 1996) has revealed for the first time, that the specific tension of muscle fibers varies across fiber type and as a function of altered levels of physical activity. Therefore it is expected that a selective reduction in the percentage and area of Type II fibers will result in a considerable loss of power output with aging.

A loss of muscle power has been shown to have profound effects on functional activities such as speed of walking up stairs, standing up from a chair and gait speed (Bassey et al., 1992). Given that recovering balance after a trip or slip requires the application of a large amount of force in a short period of time, muscle power should be a significant factor in risk of falling (Evans & Campbell, 1993). This hypothesis is supported by previous research which demonstrates a clear relationship between maximal muscle power and a static balance test (Bassey et al., 1992).

Falling is known to be one of the most serious problems facing older persons (Maki et al., 1990). The fractures, surgical procedures, hospitalisation, and complications, which often result from such falls, ensure that falling remains the leading cause of accidental death in the 65+ age group. In terms of incidence of falling, approximately one-third of all persons over the age of 65 falls at least once per year (Baker & Harvey, 1985). Although falling is a complex and multi-factorial problem, the decline in muscular strength and power has been suggested as a significant factor (Evans & Campbell, 1993; Era 1988).

There is a need for further research into the effects of aging on maximal power production and whether specific resistance training will be effective for slowing or even reversing the loss of fast twitch fiber area and number which occurs currently in our older people. Maximal power training may have a greater effect on functional capacity and the performance of daily activities than other more traditional methods such as heavy resistance exercise.

The purpose of this study was to examine the effects of a 10-week periodized resistance training program whose program variables were manipulated to simultaneously train for three dimensions of muscle characteristics: hypertrophy, maximal force production and maximal power output. It was hypothesized that such a program would lead to increases in maximal power production in both younger and older men as a result of increased muscle size, alterations in muscle

fiber characteristics, as well as quantitative and qualitative changes in neural activation.

## METHODS

### Subjects

Eighteen healthy men, drawn from two age groups; young men (YM) ( $30 \pm 5$ ;  $n=8$ ) (mean age  $\pm$  SD years) and old men (OM) ( $61 \pm 4$ ;  $n=10$ ), volunteered as subjects for the study. The subjects were carefully informed about the design of the study with specific information on possible risks and discomfort that might result. Thereafter, the subjects signed a written consent form (Appendix G) prior to participation in the project. The study was approved by the Institutional Review Board for use of Human Subjects, The Pennsylvania State University, USA. Medical control and quantification of the physical activity (via a questionnaire) revealed that all subjects were healthy and habitually physically active. To keep fit they had taken part in various recreational physical activities such as walking, jogging, aerobics or biking but none of the subjects had any background in regular strength training or competitive sports of any kind. None of the subjects were taking medication, which would have been expected to affect physical performance. The physical characteristics of the two subject groups before and after the training period are presented in Table 7.1.

**Table 7.1** Physical characteristics of the two subject groups before and after 10 weeks of resistance training.

Age Group	YM		OM	
	Mean	SD	Mean	SD
age	29.75	5.34	61.00 <sup>a</sup>	4.40
height	177.17	5.21	177.09	7.18
pre-weight (kg)	88.38	12.34	85.74	13.29
post-weight (kg)	90.48	13.86	86.00	13.99
pre-body fat (%)	17.04	6.79	20.46	4.36
post-body fat (%)	17.73	5.33	21.41	3.72
pre-lean body mass (kg)	160.74	14.83	151.71	23.78
post-lean body mass (kg)	160.25	15.86	148.84	24.43

<sup>a</sup> indicates significant difference between YM and OM. No other significant differences between groups or pre to post training.

### Experimental Design

The total duration of the study was 13 weeks. The subjects were tested on five different occasions using identical protocols. The first three weeks of the follow-up was used as a control period during which time no strength training was carried out or any other change to the subjects' normal work and recreational physical activities. Thereafter, the subjects began a supervised

strength training intervention for a period of 10 weeks. The measurements were taken during the control and experimental training period at weeks -3 (T-3), 0 (T0), 3 (T+3), 6 (T+6), and 10 (T+10).

## **Testing Protocols**

### **Anthropometry**

All anthropometric measurements were obtained by the same investigator on the right side of the subjects' body. Skinfold thicknesses were obtained with a Harpenden skinfold caliper (H.E. Morse Co., 10 g/mm constant pressure) at the chest, mid-axillary, abdomen, supriliac, subscapula, triceps, and thigh following the procedures described by Lohman et al. (1988). Repeated trials were performed until two measures within 1 mm were obtained, with the mean of these two measures being utilized. The Jackson and Pollock (1985) seven site equation was used to estimate body density and percent body fat was subsequently calculated using the Siri (1956) equation.

### **Isometric Squat**

Maximal isometric force and maximal rate of isometric force development (mRFD) in the force-time curve was measured while the subject attempted to push upwards against a fixed bar positioned across the shoulders. The bar of a PPS was used and positioned at a height such that the subject's knee and hip angles were 90 and 110 degrees, respectively. The force output was recorded using resistive force transducers in series (Entran, NJ) with a chain securing the bar at the appropriate height. The subjects were instructed to push upwards against the bar with their maximal force as fast as possible during a period of 2.5 - 5.0 s. Three to four maximal trials were completed for each subject until no further increases in peak force were produced. Maximal peak force was defined as the highest value of the force (N) recorded during the pushing movement. The force-time analysis included the calculation of the maximal rate of force development (mRFD; N.s<sup>-1</sup>)(Viitasalo et al., 1980) defined as the greatest increase in force over a given 50 ms period.

### **1RM Squat Test**

All squats were performed in the PPS to limit the range of motion to the vertical plane. Foot placement was maintained at shoulder width with the heels placed directly below the bar. The subjects were asked to squat to a position where the angle between the femur and tibia was 90 degrees as measured by a goniometer. The 90 degrees knee angle was accurately controlled and the range of motion standardised for all subjects. The bottom stoppers of the PPS were set just below the relevant knee angle and the experimenter monitored the depth of the squat. If during an attempt,

contact between the bar and stoppers was evident, the lift was disallowed and the same mass was attempted again. The one repetition maximum (1RM) was defined as the weight, which could be successfully lifted no more than one time without failure. A lift was deemed unsuccessful under the following criteria: (1) any lift which did not incorporate the full range of motion; (2) any lift not performed primarily by the specified muscle groups with the addition of momentum; and (3) any movements which compromised the integrity of the lift (Charette et al., 1991; Shaw et al., 1995). Testing began with the subject completing a set of 3-6 repetitions at approximately 50% of the expected 1RM followed by a set of approximately 75% of 1RM. Thereafter, the subject performed single repetitions as the load was incremented with 20, 10, 5, 2.5 and then 1.25 kg weights until failure occurred or the subject and tester were satisfied that no greater load could be successfully lifted. All subjects were given at least 3 minutes rest between all lifts to ensure they had fully recovered prior to attempting another lift. The maximal load lifted was recorded as the subject's 1RM squat and this normally occurred within 3-6 attempts. Experienced spotters were in attendance throughout all lifts to ensure the subject's safety and to provide vocal encouragement for a maximal effort by the subject.

### **Squat Jump**

Squat jump performance under loads of bar weight (17kg), 30% and 60% of the subject's previously determined 1RM was assessed using the PPS. Subjects were placed in a position of 90 degrees knee flexion with the heels directly under the bar of the PPS. They were then instructed to push upwards attempting to jump for maximal height. Bar displacement and mass was recorded with subsequent calculation of bar velocity and acceleration as well as the force and power applied to the bar. Performance in the squat jump was quantified by three variables: peak power was calculated as the highest instantaneous power output during the jump; mean power was calculated as the average power output during the concentric phase of the jump; and peak force was calculated as the highest force output during the jump.

### **Electromyography**

Electromyographic (EMG) activity during the isometric squat and squat jump tests was recorded from the vastus lateralis (VL) and vastus medialis (VM) of the right and left legs. Two active silver/silver chloride, pre-gelled, disposable surface EMG electrodes (3M) separated by 2 cm were attached to the belly of each muscle on the approximate position of the motor point area determined using anatomical landmarks, and a third ground electrode was attached to the lateral malleolus. The active electrodes were aligned parallel with the direction of pull of the muscle under investigation determined as a straight line between origin and insertion. Before electrode

application each site was shaved, cleansed with alcohol and gently abraded. An ink pen was used to mark the positions of the electrodes. These marks were checked at every subsequent training or testing session and if necessary ink was reapplied to ensure they remained visible throughout the entire 13-week experimental period. These marks were to ensure the same electrode positioning at each test. The EMG signals were amplified using a Noraxon EMG amplifier (Noraxon, Phoenix, AZ) and the amplified myoelectric signals and force transducer output were collected at 500 Hz per channel using a 80486DX computer running Windows 3.11 and a DT21-EZ analog to digital card (Data Translation, Marlboro, MA). The digitized EMG data were stored together with the force on computer disk for later analysis. The average EMG was calculated by full wave rectification followed by integration (iEMG) over the peak force phase (500-1500 ms) of the maximal isometric action (to calculate maximum iEMG) for each muscle separately and then averaged for further analyses. Mean and median frequency of the EMG power spectrum were calculated using standard fast fourier transformation techniques.

### **Muscle Biopsy**

Muscle biopsies were obtained before the start of training and about 72 hours after the last training session. The samples were obtained from the superficial portion of the vastus lateralis muscle of the dominate leg utilizing the percutaneous needle biopsy technique of Bergström (1962) with suction (about 100 mls) as modified by Evans et al. (1982). Due to possible variation in fiber type distribution from superficial to deep and proximal to distal sites, special care was taken to extract tissue from approximately the same location for the post-training sample by using the pre-biopsy scar (approximately 0.5 cm from scar going from medial to lateral) and marked needle depth (usually 2 cm). In addition, care was taken to address concerns for biopsy samples (Blomstrand and Ekblom, 1982; Lexell et al., 1983a; Staron et al., 1983) and utilize a procedure similar to one previously published (Staron et al 1983; 1994). Muscle tissue samples were orientated in embedding medium (i.e., tragacanth gum), frozen in isopentane cooled to  $-159^{\circ}$  C with liquid nitrogen and stored at  $-85^{\circ}$  C until analyzed. Serial cross-sections (12  $\mu$ m thick) were cut on a cryostat (American Optical, Buffalo, NY) at  $-20^{\circ}$  C for histochemical analyses. Pre and post training samples were histochemically analyzed in the same staining run to avoid inter-assay variances. In our laboratory data from repeat biopsies (randomly performed) demonstrated non-significant intra-biopsy variations in fiber type distributions. Histochemical analyses used for fiber typing consisted of assaying for myofibrillar adenosinetriphosphatase (ATPase) activity at pH 4.3, 4.6, and 10.3. Muscle fiber types were divided into four groups (types I, IIa, IIab, IIb) based on the stability of their ATPase activity in the preincubation medium (Brooke and Kaiser, 1970; Staron, 1991). Fiber type percentages were calculated from the number of fibers ( $900\pm 100$ ) in the muscle

tissue sections and areas were calculated from 150 fibers and a minimum of 50 for Type IIB fibers post training when low numbers of these fibers existed. Fiber analyses were completed with the NIH Image programme (Version 1.55b)(National Institute of Health) and a Macintosh Quadra 800 computer (Apple Corporation) interfaced to an Olympus BH-2 microscope. The perimeters of all fibers of each muscle fiber type were individually measured.

### ***Training Programme***

The subjects participated in a resistance training programme consisting of three sessions each week for a period for ten weeks. Each training session included the squat, knee extension, and knee flexion exercises on machines; trunk extension and trunk flexion exercises using free weights; and/or bench press or calf raise exercises on machines. During each week, the days were broken into a "hypertrophy day", a "strength day" and a "power day". For the hypertrophy session of the week the subjects performed sets of 8-10 RM with one-minute rest periods. This format of resistance training has been demonstrated to elicit a large response by the endocrine system and is hypothesized to provide a greater stimulus to increasing muscle size (Kraemer et al., 1987). The strength session concentrated on high intensity resistance training using sets of 3-5 RM. Performing sets of low numbers of repetitions and using a resistance close to the subject's 1 RM has been shown to produce gains in maximal strength (Häkkinen and Komi, 1985a). The third training session of the week was designed to specifically increase maximal power output. For this session the subjects performed the squat and the knee extension exercises with lower loads but for these exercises the subjects were instructed to complete the concentric phase of the movement "as fast and powerful as possible" for 6-8 reps per set. All the exercises were performed using concentric muscle actions followed by eccentric actions during the "lowering" phase of the movement. Each session the subjects performed 3-6 sets of each exercise. The volume of the training progressively increased throughout the 10-weeks of training, a so-called periodized program.

During the 10 week training period the subjects continued taking part in physical activities such as walking, jogging, or biking 1-2 times per week in a similar manner to what they were accustomed to before this experiment.

### ***Statistical Analysis***

Standard statistical methods were used for the calculation of means and standard deviations (SD). The data were then analyzed utilizing analysis of variance (ANOVA) with repeated measures and age group as a between subjects factor. Probability adjusted t-tests were used for pair-wise comparisons when appropriate. Pearson product moment correlation coefficients were calculated to

assess relationships between variables. An alpha level of  $p \leq 0.05$  was used as the criterion for establishing statistical significance.

## **DELIMITATIONS**

1. The samples chosen for this study were limited to adult males in the State College region of Pennsylvania.
2. Only four muscles of the quadriceps group of each leg were analysed using myoelectric techniques (vastus lateralis and medialis of the left and right legs).

## **LIMITATIONS**

In addition to limitations arising from the above:

Sample size was limited to eighteen subjects due to the expense of the testing and training procedures and the difficulty in recruiting men willing to undergo the muscle biopsy procedure.

A stretch shortening cycle movement was not used for the determination of 1RM or performance of the jump squats measured by the PPS because of possible risks of performing heavy SSC movements for the older men.

The training intervention was limited to ten weeks due to the time commitment and expense in training this number of subjects for a longer period.

The PPS restricts movement to the vertical plane. However, the majority of the resistance training movements and most daily activities are not restricted in this manner. Testing on the PPS is therefore not specific to many of the training movements used in this regard. This may have influenced the training adaptations resulting from the training programme.

Surface myoelectric techniques were used to estimate underlying muscle function particularly gross muscle action through iEMG. Increases in iEMG cannot be specifically attributed to increases in recruitment and/or rate coding or perhaps some other factors (e.g. temperature) with certainty, particularly the relative contributions of each mechanism.

The mean and median power frequency of the surface EMG was used as an indicator of changes in recruitment frequency.

Force output in the squat jumps was measured based on the mass of the bar and acceleration derived from the encoder system rather than directly by a force transducer.

# RESULTS

## ***Anthropometry***

Body mass and the percentage of body fat remained statistically unaltered during the experimental period in both subject groups (Table 7.1).

## ***Isometric Squat***

Peak force during the isometric squat was significantly higher for the YM compared with the OM at all test occasions (Figure 7.1). Peak force remained unchanged during the three-week control period for both YM and OM (Figure 7.1), however, over the 10 weeks of resistance training there were significant increases (Figure 7.1). Pre (T0) and post (T+10) measures of peak force and the percentage change are shown in Table 7.2. Both the YM and OM produced significant increases in peak force between the T0 and T+10 testing occasions, however, there were no significant differences between the YM and OM in the percentage change pre to post.

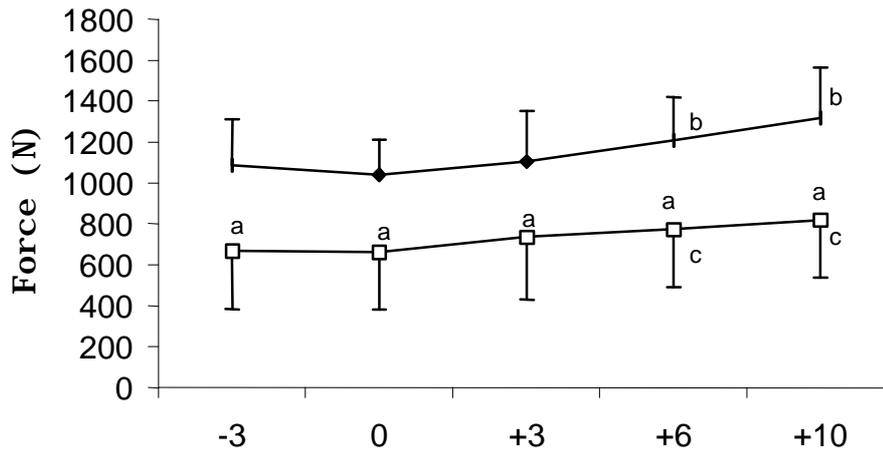
There were no significant differences in mRFD between the YM and OM at any of the testing occasions and there were no statistically significant differences in mRFD measured over the control and training period. Neither group showed statistically significant changes between any of the testing occasions in the averaged iEMG (Table 7.2), mean or median EMG frequency measured during the isometric squat. At T0, T+3 and T+10 iEMG measured in the YM was significantly higher than that of the OM.

**Table 7.2** Peak force and iEMG produced by YM and OM during the isometric squat test performed pre and post 10 weeks of resistance training.

	Young men (n=8)			Old men (n=10)		
	Pre	Post	%change	Pre	Post	%change
Peak Force (N)	1040±171	1318±247	23±15 <sup>b</sup>	661±280 <sup>a</sup>	820±281 <sup>a</sup>	40±42 <sup>b</sup>
IEMG (mV)	258±76	308±124	40±47	190±34 <sup>a</sup>	204±51 <sup>a</sup>	43±64

<sup>a</sup> indicates significance difference between young and old men at pre or post test

<sup>b</sup> indicates significant change pre to post training



**Figure 7.1** Peak force output during the isometric squat tested over a 3-week control period and 10 weeks of resistance training in YM (◆) and OM (□). <sup>a</sup> indicates a significant difference between YM and OM, <sup>b</sup> indicates a significant change from T0 in the YM, and <sup>c</sup> indicates a significant change from T0 in the OM.

### 1RM Squat

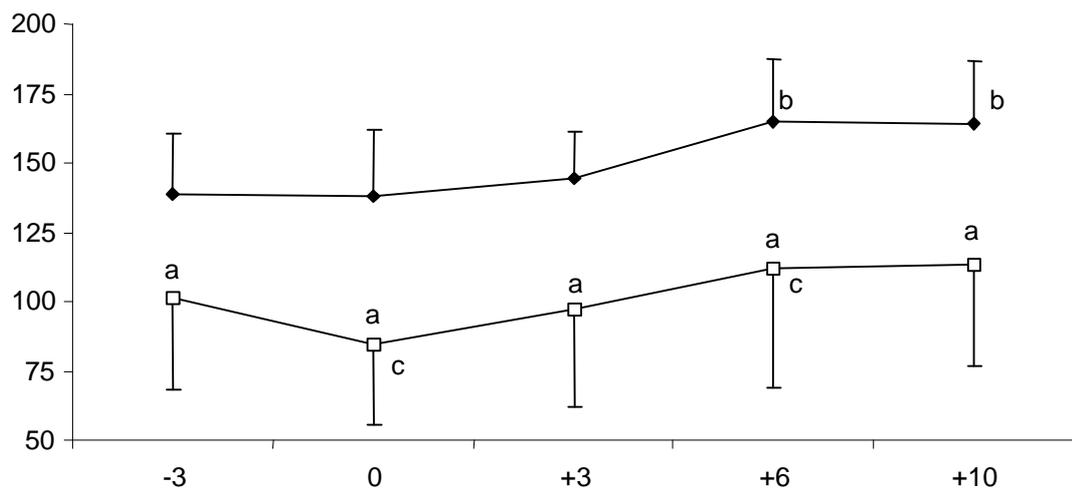
1RM squat strength was significantly higher for the YM compared with the OM at all test occasions (Figure 7.2). Peak force remained unchanged during the three-week control period for the YM and decreased significantly for the OM (Figure 7.2). As such the T-3 results were used for pre to post training comparisons in the OM as they appeared more representative of their pre-training strength. Pre (T0 in YM and T-3 in OM) and post (T+10) measures of 1RM squat strength and the percentage change are shown in Table 7.2 with the YM producing a significant increase while the OM did not. Compared with T-3 the OM were significantly stronger at T+6 but were not significantly different at the T+10 testing occasion (Figure 7.2). There were no significant differences between the YM and OM in the percentage change pre to post.

**Table 7.3** Isometric squat strength in YM and OM men pre and post 10 weeks of resistance training.

	Young men (n=8)			Old men (n=10)		
	Pre (T0)	Post (T+10)	%change	Pre (T-3)	Post (T+10)	%change
1RM Squat Strength (kg)	138±24	164±23	19±9 <sup>b</sup>	101±33 <sup>a</sup>	113±37 <sup>a</sup>	16±27

<sup>a</sup> indicates significance difference between young and old men at pre or post test

<sup>b</sup> indicates significant change pre to post training



**Figure 7.2** 1RM squat strength tested over a 3-week control period and 10 weeks of resistance training in YM (◆) and OM (□). <sup>a</sup> indicates a significant difference between YM and OM, <sup>b</sup> indicates a significant change from T0 in the YM, and <sup>c</sup> indicates a significant change from T-3 in the OM.

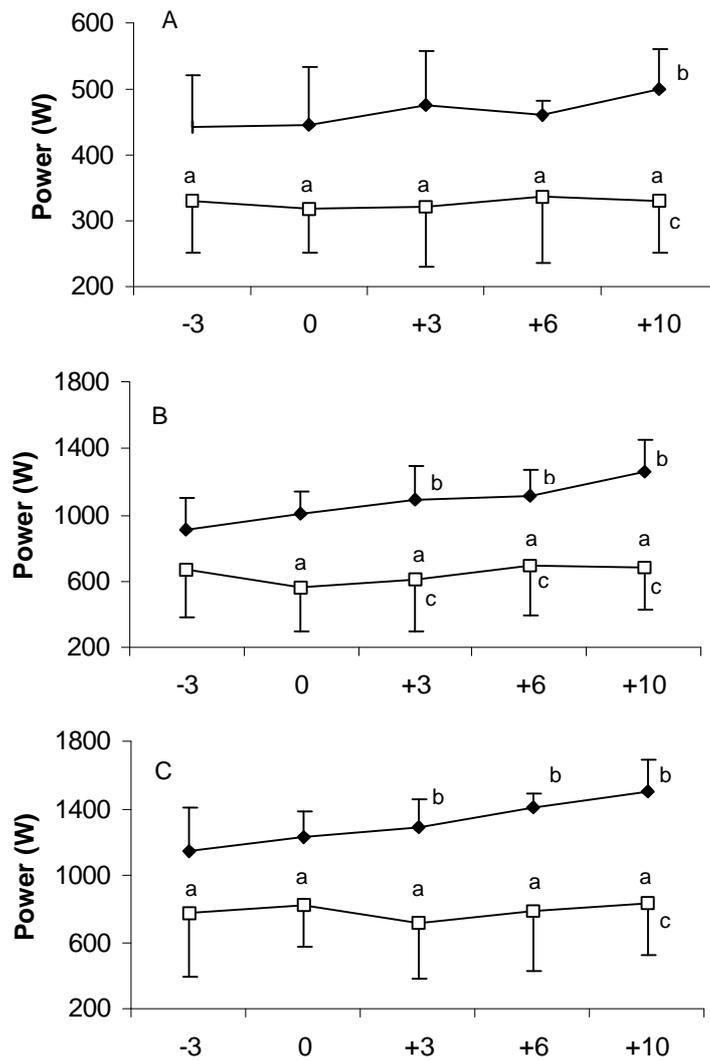
### Squat Jump

Peak power remained unchanged during the three-week control period for both YM and OM (Figure 7.3), however, over the 10 weeks of resistance training there were significant increases at all loads tested (Figure 7.3). Pre (T0) and post (T+10) measures of peak power and the percentage change are shown in Table 7.4. The YM produced significantly higher peak power output compared with the OM at all loads tested at both the pre and post training testing occasions (Table 7.4). In addition, both the YM and OM produced significant increases in peak power at all loads tested as a result of the training intervention (Table 7.4). There were no significant differences between the YM and OM in the percentage change pre to post training for any of the loads tested (Table 7.4).

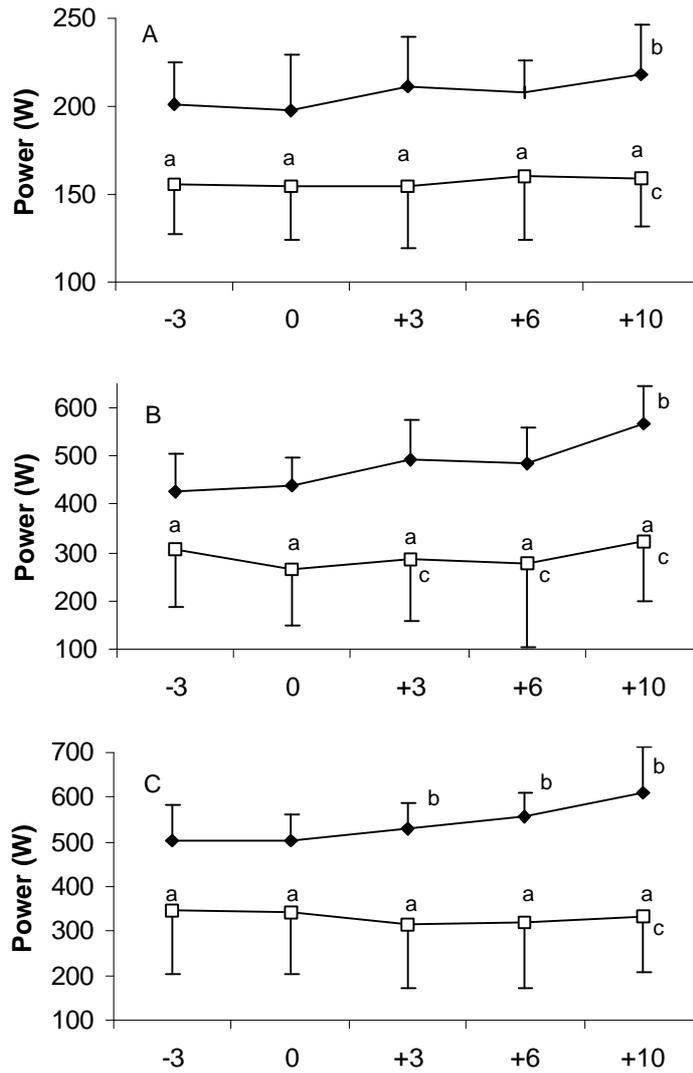
Mean power remained unchanged during the three-week control period for both YM and OM (Figure 7.4), however, over the 10 weeks of resistance training there were significant increases (Figure 7.4). Pre (T0) and post (T+10) measures of mean power and the percentage change are

shown in Table 7.4. The YM produced significantly higher mean power output compared with the OM at all loads tested at both the pre and post training testing occasions (Table 7.4). In addition, both the YM and OM produced significant increases in mean power at all loads tested as a result of the training intervention (Table 7.4). There were no significant differences between the YM and OM in the percentage change pre to post for any of the loads tested (Table 7.4).

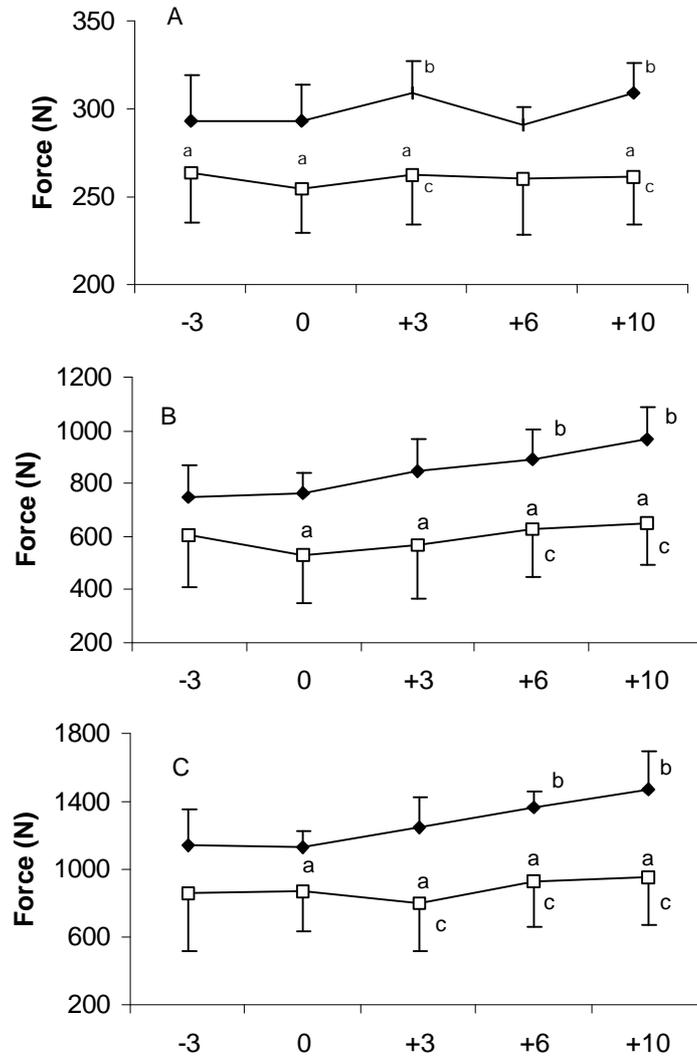
Peak force remained unchanged during the three-week control period for both YM and OM (Figure 7.5), however, over the 10 weeks of resistance training there were significant increases (Figure 7.5). Pre (T0) and post (T+10) measures of peak force and the percentage change are shown in Table 7.4. The YM produced significantly higher peak force output compared with the OM at all loads tested at both the pre and post training testing occasions (Table 7.4). In addition, both the YM and OM produced significant increases in peak force at all the loads measured as a result of the training intervention (Table 7.4). There were no significant differences between the YM and OM in the percentage change pre to post for any of the loads tested (Table 7.4).



**Figure 7.3** Peak power output of squat jumps performed with loads of A) 17 kg, B) 30% 1RM and C) 60% 1RM during a 3-week control period and 10 weeks of resistance training in YM (◆) and OM (□). <sup>a</sup> indicates a significant difference between YM and OM, <sup>b</sup> indicates a significant change from T0 in the YM, and <sup>c</sup> indicates a significant change from T0 in the OM.



**Figure 7.4** Mean power output of squat jumps performed with loads of A) 17 kg, B) 30% 1RM and C) 60% 1RM during a 3-week control period and 10 weeks of resistance training by YM (◆) and OM (□). <sup>a</sup> indicates a significant difference between YM and OM, <sup>b</sup> indicates a significant change from T0 in the YM, and <sup>c</sup> indicates a significant change from T0 in the OM.



**Figure 7.5** Peak force output of squat jumps performed with loads of A) 17 kg, B) 30% 1RM and C) 60% 1RM during a 3-week control period and 10 weeks of resistance training by YM (◆) and OM (□). <sup>a</sup> indicates a significant difference between YM and OM, <sup>b</sup> indicates a significant change from T0 in the YM, and <sup>c</sup> indicates a significant change from T0 in the OM.



**Table 7.4.** Peak power, mean power and peak force produced by YM and OM during squat jumps performed with 17kg, 30% and 60% of 1RM.

load	Young Men (n=8)			Old Men (n=10)			Old Vs Young (%)		
	pre	post	%change	pre	post	%change	pre	post	
Peak Power (W)	17kg	444±88	500±60	15±14 <sup>b</sup>	319±67	329±77	7±5 <sup>b</sup>	72 <sup>a</sup>	66 <sup>a</sup>
	30%	1011±132	1262±183	33±16 <sup>b</sup>	560±260	683±254	36±23 <sup>b</sup>	55 <sup>a</sup>	54 <sup>a</sup>
	60%	1232±150	1496±201	26±12 <sup>b</sup>	815±248	830±302	25±16 <sup>b</sup>	66 <sup>a</sup>	55 <sup>a</sup>
Mean Power (W)	17kg	198±32	218±28	11±7 <sup>b</sup>	154±31	159±28	7±5 <sup>b</sup>	78 <sup>a</sup>	73 <sup>a</sup>
	30%	437±59	566±78	34±17 <sup>b</sup>	264±116	322±122	32±12 <sup>b</sup>	60 <sup>a</sup>	57 <sup>a</sup>
	60%	502±60	610±102	19±9 <sup>b</sup>	340±135	334±125	21±15 <sup>b</sup>	68 <sup>a</sup>	55 <sup>a</sup>
Peak Force (N)	17kg	292±21	309±17	5±6 <sup>b</sup>	256±25	261±27	4±4 <sup>b</sup>	88 <sup>a</sup>	84 <sup>a</sup>
	30%	764±77	968±122	29±13 <sup>b</sup>	531±179	648±158	29±14 <sup>b</sup>	69 <sup>a</sup>	67 <sup>a</sup>
	60%	1125±96	1465±227	29±8 <sup>b</sup>	875±239	948±273	24±3 <sup>b</sup>	78 <sup>a</sup>	65 <sup>a</sup>

<sup>a</sup> indicates significance difference between young and old men at pre or post test

<sup>b</sup> indicates significant change pre to post training

### **Muscle fiber characteristics**

The percentage values for the muscle fiber distribution of the vastus lateralis muscle was significantly higher for Type IIb in the YM compared with the OM and this was apparent at both the pre and post training biopsies (Table 7.5). There were no other differences between the YM and OM either before or after the training period for percentages of the other fiber types (Table 7.5). No statistically significant changes took place in the fiber distribution of Type I during the training period either in YM or OM. The relative proportion of Type II ab increased from 2% to 6% in YM and those of Type IIb decreased in both YM from 25% to 16% and in OM from 15% to 6%. At pre training YM demonstrated larger mean fiber area of Type IIa than OM with no significant differences observed in the mean areas of the other fiber types (Table 7.6). The mean fiber area of Type I increased after the 10-week training in YM and OM as well as that of Type IIa in both YM and OM (Table 7.6).

**Table 7.5.** Mean (SD) fiber distribution of the vastus lateralis muscle before and after a 10-week resistance training period in YM and OM.

	Young Men (n=8)		Old Men (n=7)	
	Pre	Post	Pre	Post
Type I (%)	41 ± 15	41 ± 9	48 ± 9	46 ± 13
Type IIa (%)	32 ± 12	37 ± 15	35 ± 13	44 ± 13
Type IIab (%)	2 ± 1	6 ± 7 <sup>a</sup>	2 ± 1	4 ± 3
Type IIb (%)	25 ± 7 <sup>b</sup>	16 ± 8 <sup>a b</sup>	15 ± 12	6 ± 6 <sup>a</sup>

<sup>a</sup> Significant difference pre to post training.

<sup>b</sup> Significant difference compared with the group of old men at that time point.

**Table 7.6.** Mean + SD fiber areas of the vastus lateralis muscle before and after a 10-week strength training period in YM and OM.

	Young Men (n=8)		Old Men (n=6)	
	Pre	Post	Pre	Post
Type I ( $\mu\text{m}^2$ )	3757 + 704	4618 + 831 <sup>a</sup>	4091 + 1354	5044 + 862 <sup>a</sup>
Type IIa ( $\mu\text{m}^2$ )	4594 + 518 <sup>b</sup>	5775 + 1087 <sup>a</sup>	3879 + 323	5337 + 851 <sup>a</sup>
Type IIab ( $\mu\text{m}^2$ )	4883 + 1526	4027 + 962	4209 + 889	5200 + 918
Type IIb ( $\mu\text{m}^2$ )	4146 + 849	4713 + 1047	4220 + 1566	5027 + 774

<sup>a</sup> Significant difference pre to post training.

<sup>b</sup> Significant difference compared with the group of old men at that time point.

### **Correlation analysis**

A number of significant correlation coefficients were observed between the subjects' age, maximal strength, maximal power, and muscle fiber characteristics. Peak isometric force and age were significantly correlated at both the pre ( $r = -0.747$ ,  $p \leq 0.01$ ) and post ( $r = -0.748$ ,  $p \leq 0.01$ ) training tests, however, there was no relationship between age and change in isometric force with training. Peak isometric force pre-training was negatively correlated ( $r = -0.599$ ,  $p \leq 0.05$ ) with the percentage change in peak isometric force resulting from the training.

For the squat jump tests, peak force, mean and peak power output at all three loads were significantly correlated ( $r = -0.741$  to  $-0.866$ ,  $p \leq 0.01$ ) with age. The strongest correlation was between age and peak power measured for the 30% ( $r = -0.866$ ,  $p \leq 0.01$ ) and 60% ( $r = -0.866$ ,  $p \leq 0.01$ ) loads. There were no significant relationships between age and the percentage change pre to post training of any of the force or power measures. Strong positive correlation coefficients ( $r = 0.711$  to  $0.985$ ,  $p \leq 0.01$ ) were observed between mean power, peak power and peak force measured during the squat jumps at the three loads. Peak force measured during the isometric squat was positively correlated ( $r = 0.711$  to  $0.854$ ,  $p \leq 0.01$ ) with the entire squat jump performance measures. The percentage change over the training period in peak power produced during squat jumps with the 60% 1RM load was negatively correlated with the pre-training peak power output for the 30% 1RM ( $r = -0.524$ ,  $p \leq 0.05$ ) and 60% 1RM ( $r = -0.566$ ,  $p \leq 0.05$ ) loads.

Fiber distribution was related to age and a number of the performance measures. The percentage of Type IIb fibers was inversely related to age both pre ( $r = -0.539$ ,  $p \leq 0.05$ ) and post ( $r = -0.574$ ,  $p \leq 0.05$ ) training. No other fiber type percentages were related to the age of the subjects. Type I fiber percentage pre-training was negatively correlated with Type IIa percentage pre-training ( $r = -0.634$ ,  $p \leq 0.05$ ) as well as the percentage change in Type I pre to post training ( $r = -0.658$ ,  $p \leq 0.05$ ). After the training period, Type I percentage was negatively correlated with the post-training peak power measured at loads of 17kg ( $r = -0.574$ ,  $p \leq 0.05$ ), 30% 1RM ( $r = -0.607$ ,  $p \leq 0.05$ ), and 60% 1RM ( $r = -0.603$ ,  $p \leq 0.05$ ) as well as mean power measured at a load of 17kg ( $r = -0.558$ ,  $p \leq$

0.05), 30% 1RM ( $r = -0.568$ ,  $p \leq 0.05$ ), and 60% 1RM ( $r = -0.552$ ,  $p \leq 0.05$ ).

Type IIa fiber percentage pre-training was negatively correlated with the percentage change in Type IIa pre to post training ( $r = -0.574$ ,  $p \leq 0.05$ ). Type IIb fiber percentage pre-training was positively correlated with peak isometric force both pre ( $r = 0.607$ ,  $p \leq 0.05$ ) and post ( $r = 0.553$ ,  $p \leq 0.05$ ) training as well as peak power measured post training at all three loads ( $r = 0.528$  to  $0.618$ ,  $p \leq 0.05$ ) and mean power measured for the 30% ( $r = 0.589$ ,  $p \leq 0.05$ ) and 60% ( $r = 0.535$ ,  $p \leq 0.05$ ) 1RM loads. Type IIb fiber percentage post-training was positively correlated with peak isometric force both pre ( $r = 0.568$ ,  $p \leq 0.05$ ) and post ( $r = 0.677$ ,  $p \leq 0.01$ ) training and with peak power produced at loads of 30% ( $r = 0.535$ ,  $p \leq 0.05$ ) and 60% ( $r = 0.529$ ,  $p \leq 0.05$ ) 1RM at the post-training test.

Fiber area was also related to age and a number of the performance measures. The mean area of Type IIa fibers was inversely related ( $r = -0.539$ ,  $p \leq 0.05$ ) to age at the pre-training test. There were no other significant correlation coefficients between age and fiber type areas. Pre-training Type I fiber area was inversely related ( $r = -0.669$ ,  $p \leq 0.01$ ) to the change pre- to post-training of Type I fiber area and directly related ( $r = 0.556$ ,  $p \leq 0.05$ ) to the change pre- to post-training of Type IIa fiber area. Prior to the training, Type IIa fiber area was positively correlated with peak power measured during the squat jump at loads of 30% ( $r = 0.632$ ,  $p \leq 0.05$ ) and 60% ( $r = 0.616$ ,  $p \leq 0.05$ ) 1RM. After the training period, Type IIa fiber area was not related to any of the performance variables. Pre-training Type IIb fiber area was negatively correlated ( $r = -0.768$ ,  $p \leq 0.01$ ) with the percentage change over the training period in Type IIb area. In addition, Type IIb fiber area was positively correlated with the percent change in peak power at the 30% ( $r = 0.600$ ,  $p \leq 0.05$ ) 1RM load and percent change in mean power at the 60% ( $r = 0.541$ ,  $p \leq 0.05$ ) 1RM load pre- to post-training.

## DISCUSSION

The periodized strength training program used in this study was composed of a mixture of exercises for the development of muscle hypertrophy, maximal peak force or strength, and maximal power output. As a result, there were significant increases in maximal isometric force in both young and older men but not in isometric rate of force production performance from the squat position. While the gains in maximal isometric strength were not accompanied by any significant increases in the voluntary neural activation of the quadriceps muscles there were significant enlargements in muscle fiber areas of types I and IIa in both young and older men. The present training also led to significant decreases in the muscle fiber proportion of Type IIb in both young

and old men and an increase of Type IIab in young, while the relative proportion of the two main fiber types remained statistically unaltered. A principal aim of this study was to examine maximal muscle power in young and old men and the training adaptations, which could be elicited by a resistance training programme. Peak force, mean and peak power output during the squat jump were significantly higher in the young men at all the loads tested and this remained so after the training period. Both young and old men adapted to the training intervention with significant and relatively large increases in peak force, mean and peak power output, however, the percentage changes were not significantly different between the young and old groups.

It is well known that muscle strength and power decrease with increasing age (Bosco and Komi, 1980; Clarkson et al., 1981; Thelen et al., 1996). This was supported by the current study in which the older men produced only 64% as much force in the isometric squat as that of the young men prior to the resistance training (Table 7.2). Further, this difference between young and old was not altered by the training as the OM could only produce 62% of the isometric force of the YM at the post-training testing (Table 7.2). Both groups produced relatively large increases in isometric strength over the 10 weeks of resistance training and this is consistent with previous research involving both young (Häkkinen and Komi, 1985a, Staron et al., 1994) and old (Fiatarone et al., 1990; Frontera et al., 1988) subjects. However, there was no significant difference in the percentage change exhibited by the YM versus OM. The mean percentage change by the OM was 40% (Table 7.2) which is larger than the 23% (Table 7.2) change by the YM but there was considerable variability for the OM with the standard deviation of percentage change being 42% (Table 7.2); a resulting coefficient of variance of 105%. This may have accounted for a lack of significance for the difference between the groups and also suggests that older subjects exhibit greater variability in their strength adaptation to a resistance training programme. It is interesting, however, that this variability in adaptation was not evident in any of the squat jump measures and may be more a reflection of the older subjects having difficulty performing the isometric squat test. What is clear is that the resistance training programme used in this study resulted in meaningful increases in isometric strength of the hip and knee extensors both in young and old men.

Both neural and hypertrophic changes may have resulted in the increased isometric force capacity, which was observed (Moritani and DeVries, 1979). However, no significant changes in iEMG pre to post training were detected (Table 7.2) although such resistance training induced changes have been reported in many studies (Häkkinen and Häkkinen, 1995; Higbie et al., 1996; Moritani and DeVries, 1979). The present results are consistent with that reported by Narici et al. (1996) in which subjects increased isometric knee extension torque by 30% after 6 months of resistance training and yet there was no change in iEMG. At both the pre and post training test

occasions the quantity of EMG was significantly higher for the YM compared with the OM (Table 7.2) and this may explain in part the difference in their isometric strength. However, when examining the changes in neural activation over the course of the training there were large (40% and 43% for YM and OM respectively)(Table 7.2) yet non-significant increases. The variability in the iEMG measurements was considerable (Table 7.2) and so the changes were not statistically significant. There were, however, significant increases in the size of both the Type I and Type IIa muscle fibers in both the YM and OM and this would have accounted for a proportion of the increase in isometric strength.

It is important to point out that when sensitive techniques such as fiber area determination by muscle biopsy (Aniansson & Gustavsson 1981; Charette et al., 1991; Frontera et al., 1988) or muscle cross-sectional area determination by CT, MRI or ultrasound scan (Fiatarone et al., 1990; Frontera et al., 1988; Häkkinen et al., 1996; Sipilä & Suominen, 1995) have been utilized, muscle hypertrophy has also been shown to account for a considerable portion of the strength gains not only in young but also in the elderly. Skeletal muscles of elderly people seem to retain the capacity to undergo training-induced hypertrophy when the volume, intensity and duration of the training period are sufficient (Fiatarone et al., 1990; Frontera et al., 1988; Häkkinen et al., 1996).

A transformation of Type II muscle fiber subtypes and no change in the percent of Type I fibers was observed pre to post training for both the younger and old men. This Type II subtype transformation going from Type IIb to IIab to IIa has been previously observed only in younger men (Adams et al., 1993; Kraemer et al., 1995; Staron et al., 1991; 1994). Such muscle fiber transformations indicate that a large amount of the muscle tissue mass was recruited using this study's training protocol with alterations in myosin ATPase isoforms and myosin heavy chains (Adams et al., 1993; Kraemer et al., 1995; Ploutz et al., 1994; Staron & Johnson 1993; Staron et al., 1989; 1991). The remaining IIb muscle fibers were either not recruited by the heavy resistance exercise program or if recruited have higher oxidative enzyme levels and had not yet made the protein changes needed for isoform transformation (Ploutz et al., 1994; Staron et al., 1991). Prior studies in younger men with longer training periods (i.e., > 3 months) have typically demonstrated the absence or very low percentages (< 2%) of Type IIb muscle fibers after a heavy resistance training program (Adams et al., 1993; Kraemer et al., 1995; Staron et al., 1991). The results of this study are similar to Staron et al. (1994) which indicate that with shorter training periods, muscle fibers make only partial transformation in the Type IIb fiber population.

As expected muscle fiber hypertrophy with resistance training was observed in both the younger and older subjects (Brown et al., 1990; Frontera et al., 1988). Both younger and older subjects demonstrated significant increases in their Type I and IIa muscle fiber areas with resistance

training. The concomitant hypertrophy of both the Type I and IIa subtypes with the use of only a heavy resistance training program is consistent with prior studies in younger men (Adams et al., 1993; Kraemer et al., 1995). The wider range of resistance loads used in this periodized program may have encompassed recruitment of both slow and fast motor units. Interestingly, the relative magnitude of muscle fiber hypertrophy in Type I and IIa fibers were similar in both the younger and older subjects. The lack of differences at the cellular level may indicate that protein metabolism for men approximately 60 years old in response to a periodized resistance training program is not compromised despite a smaller absolute amount of muscle mass. This might be due to the adequate intake of protein and total calories (which were monitored for adequacy in this study) to support the anabolic changes at the cellular level (Campbell et al., 1995; Fiatarone et al., 1994; Meredith et al., 1992). Thus, the use of a periodized resistance training program at essentially the threshold of dramatic age effects in active 60 year olds may be effective in offsetting continued declines as demonstrated in the age-related differences in absolute muscle mass.

The time course of isometric force production as indicated by measures such as mRFD has been shown to be a sensitive indicator of changes resulting from maximal power training (Häkkinen & Komi, 1985b) as well as distinguishing between young and old subjects (Häkkinen & Häkkinen, 1991; Thelen et al., 1996). That no changes with training nor differences between young and old subjects were observed in this study was surprising, however, this may have occurred because a multi-joint movement, the squat, was used rather than isometric knee extension (Häkkinen & Komi, 1985b; Häkkinen & Häkkinen, 1991) or plantar flexion (Thelen et al., 1996) as has been the case in the previous studies cited. Although the squat position is more functionally specific to the squat jump and daily activities such as climbing stairs or rising from a chair, there is the problem in measuring isometric force production in that the subject is already supporting the body weight and thus the isometric action does not begin from a relaxed muscle state as for isometric knee extension.

The isometric squat test was intended to indicate differences in isometric strength and the time course of force development, however, the squat jump is a dynamic test of maximal power output and even more specific to functional daily activities. In terms of maximal power output, the old men were capable of around 55% to 77% of the performance of the young men in the squat jump (Table 7.4) and the difference between YM and OM was still observable after the training, however, for all measured variables at all loads tested the performance of the old relative to the young men actually decreased slightly (Table 7.4).

Power and force output increased as a result of the training in both the YM and OM and at all the loads tested but the percentage changes pre to post were the same regardless of age group. Therefore, the periodised programme designed to increase muscle size, strength and maximal power

was effective at increasing performance in the squat jump resulting in considerable increases in power output in both young and old men. Such a result is important because muscle strength and power have been shown to be related to functional performance of daily living activities such as walking, climbing stairs, and rising from a chair (Bassey et al., 1992). Therefore, the resistance training programme used in the current study may be effective for improving and/or maintaining the functional capacity of older people. Further, Evans & Campbell (1993) have suggested that muscle strength and power may be related to risk of falling and thus, the findings of this study may have application in the prevention of falls by the elderly.

It can be concluded from the results of this study that old men have a similar capacity to increase performance in maximal power activities to young men if a resistance training programme of appropriate intensity and duration is completed. Although similar changes were observed between YM and OM there were differential changes across the loads tested. Although the heavier 30% and 60% 1RM loads produced similar percentage increases of 19 to 36%, both force and power output increases were only 4 to 15% for the lightest load of bar weight only (17kg). This is most probably a reflection of the loads used in training which were 60% 1RM or higher and thus a load specific training adaptation is observed, with only small but significant increases in performance with the lower load resulting from training. This result is very much in agreement with previous research reporting load (Kaneko et al., 1983; Moritani et al., 1987) and velocity (Kanehisa and Miyashita, 1983; Mofroid and Whipple, 1970) specific adaptations to resistance training.

As was the case for the isometric squat test, there were no differences observed in the iEMG or frequency content of the electromyographic signal recorded from the quadriceps during the squat jumps. The variability within and between subjects was even greater than for the isometric test with problems of changing muscle length and movement artifact. As such the effects of load, age, and training could not be statistically distinguished. However, future research may prove more fruitful in this regard if agonist to antagonist muscle activation is examined as suggested by Carolan and Cafarelli (1992). Any neural adaptations resulting in increased power output in the current study may have resulted more from improved intermuscular coordination (Schmidtbleicher, 1992; Young, 1993) rather than changes in the quantity and frequency of intramuscular activation.

The work of Bobbert and Van Soest (1994) has particular relevance to the findings of the current study. Using computer modeling it was determined that increasing muscle strength alone does not increase vertical jump performance without modification to the neural control of the movement (Bobbert and Van Soest, 1994). Presumably, such modification would occur in the human as a result of practicing the skill of jumping. As the training programme used in the current

study combined exercises designed to increase muscle strength with those designed to increase maximal power both strength, as indicated by the isometric and 1RM squat test, as well as power output as measured in the squat jump improved considerably in both age groups. Future research should address the relative efficiency of training solely for strength and then altering the program to train solely for maximal power versus the simultaneous strength and power training used in the current study.

With increasing age there was a decrease in all measured performance variables, however, there were no significant relationships between age and the percentage change in these variables pre to post training. Therefore, it can be concluded that within the training parameters of intensity, frequency and duration used in the current study the OM adapt at a similar rate to that of the YM. Whether this finding would hold true, particularly over longer training periods, remains to be determined. Rather than age being the determining factor in training response, initial level of strength was found to be the main determinant of the size of training adaptation both in strength and power output. This was a negative relationship, however, indicating that those subjects with lower initial strength levels produce the greatest increases in strength and power.

There were significant relationships between age and the percentage of Type IIb fibers as well as the area of Type IIa. These were negative correlations indicating that with increasing age there was a lower proportion and area of these respective sub-types of fast twitch fiber. This result supports the findings of Lexell et al. (1988) that aging results in a decrease in muscle fiber size, particularly Type II and possibly a loss of Type II fiber number. Whether this phenomenon is due exclusively to the aging process is not known but it is most probable that the decline in physical activity levels, particularly in intensity, contributes substantially to this decline. The results of the current study, although not conclusive, suggest that this effect which is commonly ascribed to “aging” can be reduced with appropriate resistance training. At the post training test the difference between YM and OM in Type IIa fiber area was not present and there was no longer a significant relationship between age and Type IIa fiber area.

In terms of relationships between fiber type and strength and power measures a number of interesting patterns were observed. The higher the percentage of Type I fibers measured pre training then the lower the subject’s peak and mean power production at the post training test. This suggests that subjects with a high proportion of slow twitch fibers have a reduced ability to increase maximal power output. In addition, subjects with larger Type I fibers exhibited smaller changes in Type IIa fibers as a result of the training. Although the relatively small numbers of subjects reduce the power of correlation analyses, the results suggest that a high proportion and size of Type I fibers translates to reduced increases in Type II fibers and improvements in maximal power production as

a result of resistance training.

Type IIb proportion was positively correlated with both strength and power measures and the area of Type IIb was positively related to the change in peak and mean power with training. Therefore, higher Type IIb characteristics appear to favour development of strength and power.

## **CONCLUSIONS**

It can be observed from the results of this study that a periodized resistance training programme composed of a combination of exercises for increasing muscle size, maximal peak force, and maximal power produced significant increases in maximal isometric and 1RM squat strength in both young and old men but no changes took place in the shape of the isometric force time curve, iEMG, or frequency content of the EMG signal. Maximal power output was increased considerably in the squat jump at all loads tested and this improvement did not appear to be effected by the age of the subjects. Although no changes in muscle activation of the agonists were detected, significant increases in the individual muscle fiber areas of Type I and IIa as well as a significant decrease in the proportions of Type IIb in both young and older subjects and an increase in Type IIab in young men was observed. Higher post training strength and power and greater improvements in muscle strength and power were observed in those subjects with higher proportions of Type II fibers and lower proportions of Type I fibers.

# **Chapter 8**

## **SUMMARY AND CONCLUSIONS**

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This thesis examined the expression and development of maximum muscular power in the human. Following an extensive review of the scientific literature, it was determined that powerful movements are the result of many interacting functions of the neuromuscular system. There were several limitations to the existing methods for measuring maximal power performance in sport and work activities. Further, the effectiveness of traditional resistance training methods for developing maximal power and athletic performance was questionable, particularly in already strength trained subjects.

The PPS was developed specifically to measure and train maximal power production in the human. A rotary digital encoder system was used to measure the kinematics of the subject's performance. This measurement system was assessed and found to be valid and reliable with greater precision and accuracy than a high speed video measurement system when determining bar displacement, velocity and acceleration. An electronic braking system was installed to reduce the impact forces experienced during landing. An evaluation of this system found that the impact force and impulse over the first 50ms of contact were significantly reduced during landing from a jump squat. It was concluded that the braking system was effective at controlling the impact forces experienced during landing.

Once the functioning of the system had been assessed a further series of four experiments were completed to investigate the expression and development of maximal power production. The first compared the kinetics, kinematics and muscle activation during ballistic (bench throw) versus traditional (bench press) resistance training movements. The peak velocity of movement, force and power output, and muscle activation were significantly higher for the ballistic movement. In particular, it was found that muscle activation began to decline over the later 40%-50% of the bench press movement resulting in greatly reduced force, power and velocity over the later phase. However, for the bench throw, the bar continued to accelerate throughout the movement and muscle

activation, force and power output were high for the entire concentric phase. It was suggested that ballistic resistance training would be more effective for increasing maximal power because the pattern of muscle activation, velocity, force and power output is more specific to that produced during powerful athletic movements.

The second experiment found that performing ballistic movements in the form of bench throws using loads spanning the concentric strength range resulted in very similar force, velocity, and power outputs to that determined for isolated muscle fibers (Hill, 1938; Faulkner et al., 1986), whole muscle in vitro (Green, 1986), and single joint high power movements (Kaneko et al., 1983). However, contrary to previous research (Bosco & Komi, 1979; Bosco et al., 1982) the SSC throw did not result in a significantly better performance than the CO throw. It was concluded that prior eccentric stretch only potentiates the early phase of the subsequent concentric movement and that the advantage is lost during the later phase. Although the force, velocity, and power curves were greater during the early concentric phase of the SSC compared with the CO throw, they converged over the remainder of the concentric phase to result in no significant difference in release velocity or height thrown. It was suggested that the ability to maintain high force output while the muscle is shortening rapidly is an important factor in maximal power performance. This further supports the efficacy of using ballistic resistance training for developing maximal power production. Although there is considerable evidence which supports a potentiation of concentric performance by a prior eccentric stretch movement, it was hypothesised that this is only of benefit in movements of short duration in both time and range of muscle shortening.

The third experiment tested the efficacy of using ballistic resistance training with already highly trained, elite jump athletes. It was found that this type of training could produce significant and meaningful improvements in vertical jump performance compared with traditional training techniques. The improvements result primarily from an increased ability to produce force throughout the concentric phase, an increased maximum rate of force development, and possibly improved SSC capability. These performance gains were produced from ballistic resistance training in which an electric brake was used to reduce the load on the downward phase and therefore the eccentric force placed on the neuromuscular system.

The final experiment compared young and older men in terms of their muscle strength, maximal power output, neural activation, muscle fiber characteristics and subsequent adaptation to a resistance training programme. It was concluded from the results of this study that a periodized resistance training programme composed of a combination of exercises for increasing muscle size, maximal peak force, and maximal power produce significant increases in maximal isometric and 1RM squat strength in both young and old men but no changes took place in the shape of the

isometric force time curve, iEMG, or frequency content of the EMG signal. Maximal power output was increased considerably in the squat jump at all loads tested and this improvement did not appear to be effected by the age of the subjects. Although no changes in muscle activation of the agonists were detected, significant increases in the individual muscle fiber areas of Type I and IIa as well as a significant decrease in the proportions of Type IIb in both young and older subjects and an increase in Type IIab in young men was observed. Higher post training strength and power and greater improvements in muscle strength and power were observed in those subjects with higher proportions of Type II fibers and lower proportions of Type I fibers. Thus, although the muscle strength and power of older men is lower than that of young men, these performance measures can be effectively increased with a resistance training programme of appropriate intensity, volume and duration.

***With reference to the current literature the results of this thesis have confirmed:***

1. When performing traditional resistance training movements there is a considerable deceleration period during the later portion of the concentric phase during which muscle activation, force, power, and velocity are markedly diminished.
2. Powerful movements of the upper body exhibit similar force, velocity, and power relationships to that previously determined for muscle fibers, whole muscle, and compound movements of the lower body.
3. For the upper body, the performance of a stretch shortening cycle enhances the force and power output of the early phase of the subsequent concentric movement.
4. Elite jump athletes respond to ballistic resistance training in a similar fashion to strength trained subjects (Wilson et al., 1993) and non-elite athletes (Lyttle et al., 1996).
5. Older men adapt to a resistance training programme with increases in muscle strength and power output. Further, increases in muscle fiber size and a shift from Type II subtypes from Type IIb to IIab and IIa was observed.

# **Chapter 9**

## **DIRECTIONS FOR FURTHER RESEARCH**

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A number of research questions have arisen out of this thesis. Following is list of these questions and possible experimental paradigms:

### ***Heavy Versus Light Loads***

A most important research question is what load is optimal for increasing maximum muscular power. Most likely, there is no optimal load but very specific training adaptations occur in response to different training loads. To elucidate the mechanisms for specific adaptations, a study is required which involves two groups, one performing ballistic resistance training with a relatively light load, say 30% MVC, and the other using a relatively heavy load of 80% MVC. Testing should involve measures of muscle activation, velocity, force and power output over a range of loads, and specific performance measures such as vertical jump and reach. It would also be enlightening to take pre and post training muscle biopsies and examine fiber type and cross-sectional area changes, myosin heavy-chain composition, and calcium activity to try and discern load and velocity specific changes at the histochemical and biochemical level.

### ***Single versus multiple repetitions***

A major advantage of ballistic resistance training over traditional weightlifting is the specificity of the movement pattern to that of maximal power movements in sport. However, as noted previously, the ballistic resistance training study completed as part of this thesis involved sets of 6 repetitions and yet it is rare if ever that an athlete jumps more than 2-3 times consecutively. In particular, all of the vertical jump tests used to assess the training adaptations involved only a single vertical jump. A much larger increase in jump performance may have resulted if sets of only 1-3 jumps were performed as part of the training intervention. Therefore, a study is required which examines completing sets of 1-3 repetitions versus 6-8 repetitions to assess which is more effective

for increasing maximal power production.

### ***Periodisation***

Although meaningful increases in jump performance were produced in the training study described in Experiment Four, there was the problem of the other weight, endurance, and volleyball skill training that was being completed concurrently. Previous research by Kraemer et al. (1995) has demonstrated clear interference effects of concurrent strength and aerobic training and it is possible that the improvements in vertical jump performance would have been much greater if only ballistic resistance training was being completed during the training period. This raises the issue of periodisation of training. Further work is required to determine the sequencing of hypertrophy, strength, and maximal power training during both the pre-season and in-season. The traditional model of periodisation stipulates that the sequence should be hypertrophy, then strength and finally power training immediately before the competition phase (Baker et al., 1994; Bompa, 1990; Mateyev, 1972; Medvedyev, 1988; Stone, 1981). This model requires further validation particularly as it relates to maximising maximal power in sports which involve a long competitive season such as football, soccer, and basketball. As evidenced in the training study using young versus old men, simultaneously training for strength and power results in considerable increased in both qualities of muscle function. However, future research should address the relative efficiency of training solely for strength and then altering the program to train solely for maximal power versus the simultaneous strength and power training used in Experiment 5.

### ***Under weighting***

This thesis addressed the use of loads equal to or greater than that used during the competitive target event. For example, when training for vertical jump, loads of body weight plus some additional resistance were used and yet one of the main test criteria was a vertical jump test with body weight as the only resistance. Future research should examine the effects of training with loads less than that encountered in the target activity. For example, what are the training adaptations when performing ballistic resistance training using jump squats where the body is actually unweighted by 30% of MVC using a pulley system or electric motor? The velocity of movement would be much faster and this may result in interesting neural and muscle tissue changes.

### ***Olympic Style Lifting***

Most strength and conditioning coaches are now using the Olympic lifts (clean and jerk, snatch) or modifications of these lifts (power clean, push press, hang clean) to develop maximal

power production from their athletes. However, the efficacy of this practice has been investigated in only a single research study (Stone et al., 1980). A controlled study is required to determine the performance, neural, and histochemical adaptations, which result from this type of training. Further, comparisons should be made with ballistic resistance methods to determine the relative effectiveness of these training modalities.

### ***Reducing the Eccentric Load***

A considerable amount of braking was used during the downwards phase of the ballistic training study described in Experiment Four. Interestingly, this did not appear to reduce the performance improvements. The role of eccentric loading on maximal power development requires further investigation by a specific comparison of eccentric braking with no braking in terms of training response.

### ***Effects of Resistance Training on Functional Capacity and Resistance to Falling in Older People***

Experiment Five demonstrated that older men have a considerable ability to increase muscle strength and power output as a result of a resistance training programme of adequate intensity and duration. What remains to be determined is if these adaptations translate into improved functional capacity in tasks such as walking, climbing stairs, and rising from a chair. Of even greater importance is to determine if the improvements in neuromuscular performance result in a reduced risk of falling or at least, is the ability to recover balance following trip or slip improved.

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# ***Appendix A***

## **PILOT STUDY: VALIDATION OF THE MEASUREMENT SYSTEM**

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### **RELIABILITY AND VALIDITY OF USING A ROTARY DIGITAL ENCODER FOR KINEMATIC MEASUREMENT DURING BALLISTIC MOVEMENTS**

#### **INTRODUCTION**

Resistance training programs have traditionally involved the monitoring of weight lifted, repetitions and sets completed. However, recent research has shown that volume of training is best quantified by the total work done (Kang, Martino, Russo, Ryder & Craig, 1996). Further, in terms of maximal power performance, the velocity of movement, force, and power output are important factors which influence the resulting training adaptations (Wilson, Newton, Murphy & Humphries, 1993; Newton, Kraemer, Häkkinen, Humphries & Murphy, 1996). Therefore, the accurate measurement of the displacement, velocity, and acceleration of the load moved during resistance training would provide further valuable information for the exercise scientist or strength and conditioning coach.

Biomechanics terms these parameters the *kinematics* of the movement and such data can be used for performance assessment, technique analysis, and monitoring of training. Kinematic analysis of the bench press (Wilson, Elliott & Kerr, 1989; McLaughlin & Madsen, 1984), Olympic lifting (Garhammer, 1978; Canavan, Garrett, & Armstrong, 1996), and squat (McLaughlin, Dillman & Lardner, 1984) have been reported all having used either cinematography or video for collection

of displacement-time data.

Another approach has been to attach an accelerometer to the load (Ratliff & Bembien, 1995) and use a forward solution (Winter, 1990) to predict the velocity and acceleration data. There is the advantage in predicting force applied based on the mass and a direct measurement of acceleration, however, accelerometers are sensitive to impacts, and the process of integration with time to produce velocity and displacement data can be prone to error.

A rotary encoder is a device which is used in numerous industrial applications and is available commercially from a number of manufacturers. It consists of a light source and sensor located either side of a slotted disk. As the disk rotates electrical pulses are generated with each pulse corresponding to a given angular displacement. When attached to a sprocket and chain system, linear displacement of the chain can be measured. Differentiation of the displacement with time produces velocity and acceleration data. If the mass is known then force output can also be calculated. Funato, Matsuo, and Fukunaga (1996) have used a rotary encoder to measure the displacement of a bar during various pull movements used in Olympic weightlifting. They were also able to calculate velocity, work and power output. Such a system offers considerable advantages by providing displacement, velocity, acceleration, force, and power data in real-time to be used in testing, training and rehabilitation.

The purposes of this study were to: a) determine the reliability, accuracy and precision of a rotary encoder system for the measurement of displacement; b) compare the displacement, velocity and acceleration data derived from a rotary encoder system with that obtained from a high speed video motion measurement system; c) compare the acceleration measured for a free falling weight with that of the known acceleration due to gravity at sea level of  $-9.81 \text{ m.s}^{-2}$ .

## **METHODS**

### ***Equipment***

#### **Plyometric Power System (PPS)**

The PPS (Plyopower Technologies, Lismore, Australia) allows traditional barbell weight training movements such as bench press and squat to be done in a dynamic, ballistic manner and has been described elsewhere (Wilson, et al., 1993; Newton et al., 1996). The machine allows only vertical movement of the bar, and metal stops can be adjusted to limit the upper and lower travel of the bar in 0.01 m increments. Linear bearings attached to either end of the bar allowed it to slide up and down two steel shafts with a minimum of friction.

As the bar was moved, the chain attached above and below, rotated a sprocket at the bottom of the PPS (Figure A.1). This sprocket in turn rotated a rotary encoder (Model E6B2-CWZ3E 600 pulse/rev, Omron Corporation, Japan). As a result, the encoder produced a 5 volt (TTL) pulse for approximately every 0.001 m of bar movement. These pulses along with a TTL signal indicating movement direction were fed into a counter timer board (Model CTM05, Computer Boards, Mansfield, MA) installed in a 80386DX computer running MSDOS (Microsoft Corporation, Redmond, WA). The counter timer card was capable of measuring pulse frequencies of up to 1MHz and time events with an accuracy of 10 microseconds.

### **High speed video motion measurement system**

A high speed camera and recorder (Peak Performance Technologies, Denver CO) were used to record a video image of the bar movement during the jump squats. The framing rate of the camera was 120 Hz. A small reflective marker was placed on the bar to aid in the digitizing of the image. The Peak Motion Measurement System Version 5.0 (Peak Performance Technologies, Denver CO) was used to determine the digital coordinates of the bar in each video frame. This data was scaled according to the length of the scale rod and then stored as displacement time data for each trial.

### **Calibration**

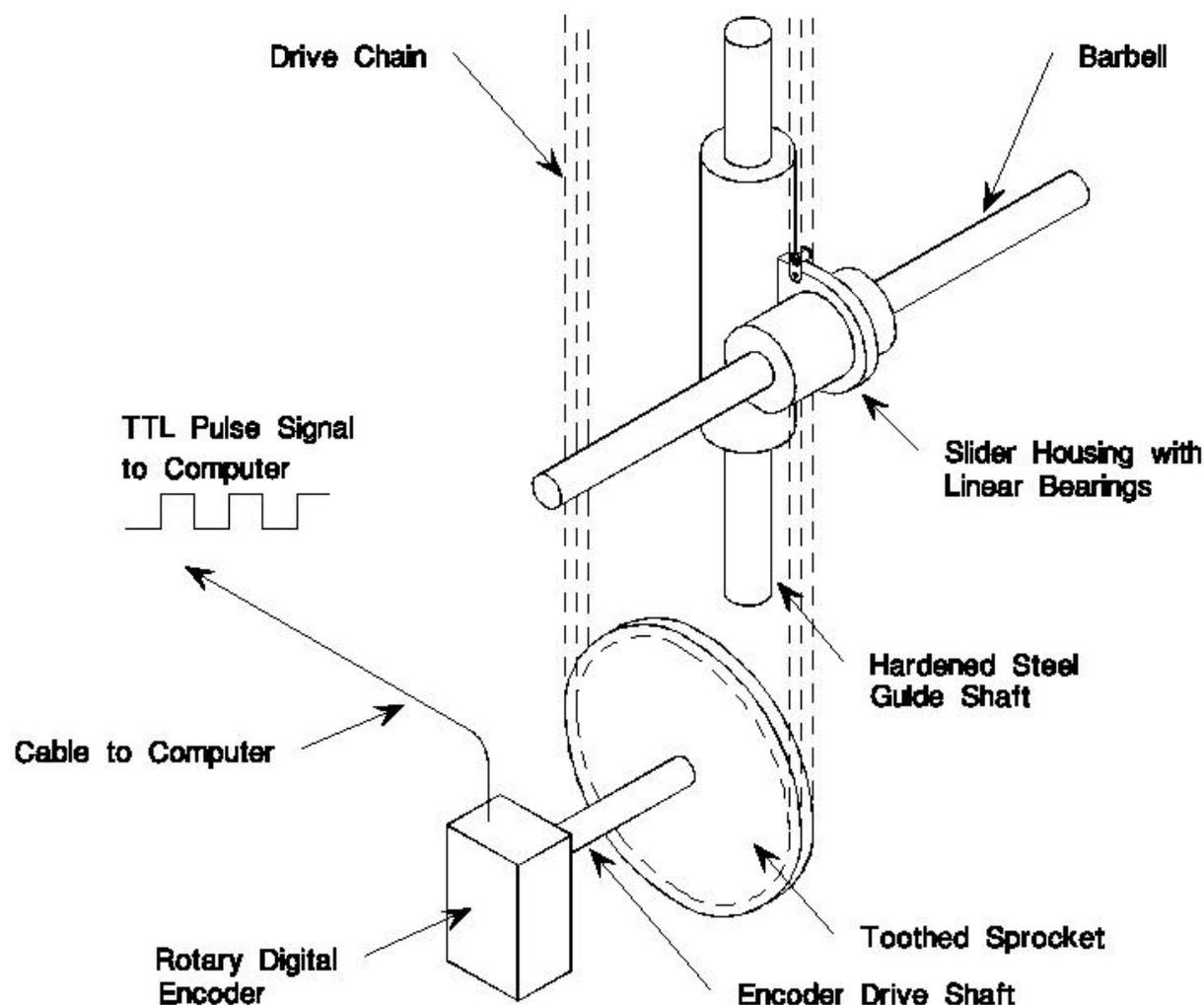
The distance encoder system was calibrated immediately prior to data collection by counting the total number of pulses produced as the bar was moved through a distance of 1.600 m. The distance travelled per encoder pulse was determined and all subsequent displacement data was calculated by multiplying the number of pulses by this calibration factor. The Peak Motion Measurement System was calibrated by recording the image of two markers separated by a vertical distance of 1.600 metres. All coordinates were then scaled relative to this distance using the Peak Motion Measurement software.

### ***Experiment A: Reliability of displacement measurement***

#### **Testing Procedures**

During the first experiment, the bar was moved up and down manually through a set distance and the displacement of the bar in each direction calculated. Steel stoppers attached above and below the bar ensured that the distance travelled was limited to the two measured distances of 0.700 m and 1.610 m. The distance between the stoppers was measured using a steel tape measure. During each repetition the number of pulses from the encoder since the last change in direction of

movement were recorded and scaled to a displacement measure in metres for the up and down directions. Two sets of 20 trials were completed on the first testing day, and a further 20 trials two days later to assess the intra-day and inter-day reliability respectively.



**Figure A.1** Schematic diagram of the rotary digital encoder attached to the Plyometric Power System.

### Statistical Analysis

Mean and standard deviation was calculated for each distance and direction. Accuracy was calculated as the difference between the mean measurement and the actual distance then divided by the actual distance and multiplied by 100. The precision of measurement was calculated as the standard deviation divided by the mean multiplied by 100. A two-way (3 trials x 2 distances) repeated measures ANOVA with the trial as the within-subject factor was used to test for statistical differences using a criterion level of  $p < 0.05$ . Inter-day and intra-day Technical Error of Measurement (TEM) and Intraclass Correlation Coefficients (ICC) were calculated according to the methods of Knapp (1992).

## ***Experiment B: Comparison of encoder system with high speed video system***

### **Testing Procedures**

A human subject performed counter movement jump squats with resistances of a light (bar weight = 17 kg), moderate (40 kg), and heavy (60 kg) load. Three trials were completed at each load. Encoder pulses were counted from the rotary encoder and bar movement was recorded on high speed video throughout each jump.

The encoder pulses were converted to displacement data by multiplying the pulse count by the calibration factor and accounting for change in movement direction. The video recording of the bar movement was digitised and actual bar displacement data calculated. Both data sets were then optimally smoothed (Jackson, 1979) using a fourth order Butterworth digital filter then differentiated, first to obtain velocity time data, then again to obtain acceleration time data. Maximum and minimum displacement, velocity, and acceleration were calculated as well as the time between each maxima and minima. The results derived from the encoder system were then compared with the “standards” calculated from the video system by calculating the TEM, TEM%, and ICC (Knapp, 1992).

To compare the displacement, velocity and acceleration data from encoder and video systems at every time point throughout the movement, the encoder data was first reduced from the original 500Hz sampling frequency to 120Hz. Linear interpolation was used to ensure that the data point derived from the encoder system was at exactly the same time as the corresponding data point from the video system. The displacement data derived from the encoder and video recording was then compared by calculating the TEM and ICC between each data set at each time point. This process was repeated for the velocity and acceleration data derived from each measurement system.

### **Statistical Analysis**

Mean and standard deviation were calculated for each measured and derived variable. Multivariate ANOVA with repeated measures was used to test for differences between the measurement system across all variables. A criterion level of  $p < 0.05$  was used to determine statistical significance.

## **Experiment C: Comparison of acceleration due to gravity measured by the encoder system with the known value of $-9.81 \text{ m.s}^{-2}$**

### **Testing Procedures**

A 20kg load was dropped under free fall conditions for a distance of approximately 2 m landing on a mat of thick sponge rubber. Ten trials were completed on one day and a further ten trials on another day. Encoder pulses were counted from the rotary encoder and converted to displacement data by multiplying the pulse count by the calibration factor. The displacement data for each trial was then smoothed using a fourth order Butterworth digital filter with a cut-off frequency of 12 Hz, then differentiated, first to obtain velocity time data, then again to obtain acceleration time data. Measured acceleration due to gravity was then determined as the minimum acceleration achieved between the time of release and the time immediately before impact with the ground. The results derived from the encoder system were then compared with the known value of 'g' at sea level of  $-9.81 \text{ m.s}^{-2}$ . The error in measurement of 'g' was calculated as follows:

$$\%error = \frac{g - \bar{a}}{g} \times 100$$

where :

$$g = -9.81 \text{ m.s}^{-2}$$

$\bar{a}$  = average measured acceleration over all trials

TEM and TEM% were calculated (Knapp, 1992) between the data collected on separate days to provide an indication of inter-day variability. .

### **Statistical Analysis**

Mean and standard deviation were calculated for measured acceleration due to gravity on days 1 and 2. A paired t-test was used to test for differences between acceleration measured on different days. A criterion level of  $p < 0.05$  was used to determine statistical significance.

## **DELIMITATIONS**

The measurement of acceleration was limited to free-fall from a height of 2 m as this was the maximum permitted by the height of the PPS allowing for 0.75 m of padding to absorb the impact of landing.

The measurement of acceleration due to gravity was limited to a mass of 20kg as it was difficult and dangerous to drop higher masses in the laboratory setup, which was used.

## LIMITATIONS

In addition to limitations arising from the above:

Direct measurement of acceleration was not possible because there was no accelerometer available in the laboratory where the experiment was conducted.

An indeterminable amount of resistance is present in the measurement system due to friction and rotary inertia of the sprockets, shafts and other rotating parts.

## RESULTS

### **Experiment A**

The mean, standard deviation, percentage accuracy and percentage precision for the two distances measured are provided in Table A.1. Best accuracy was obtained over the shorter distance (0.22%) and the worst during the upwards measurement of the 1.610 metres (0.51%). Precision of measurement was highest for the 1.610 metres distance (0.10%) and lowest during the downwards movement over 0.700 metres (0.44%). TEM was 0.9 mm and 0.8 mm intra-day and inter-day respectively, ICC was 0.9999 and 0.9999 intra-day and inter-day respectively. There were no significant differences between measurement of either distance either within or between days.

### **Experiment B**

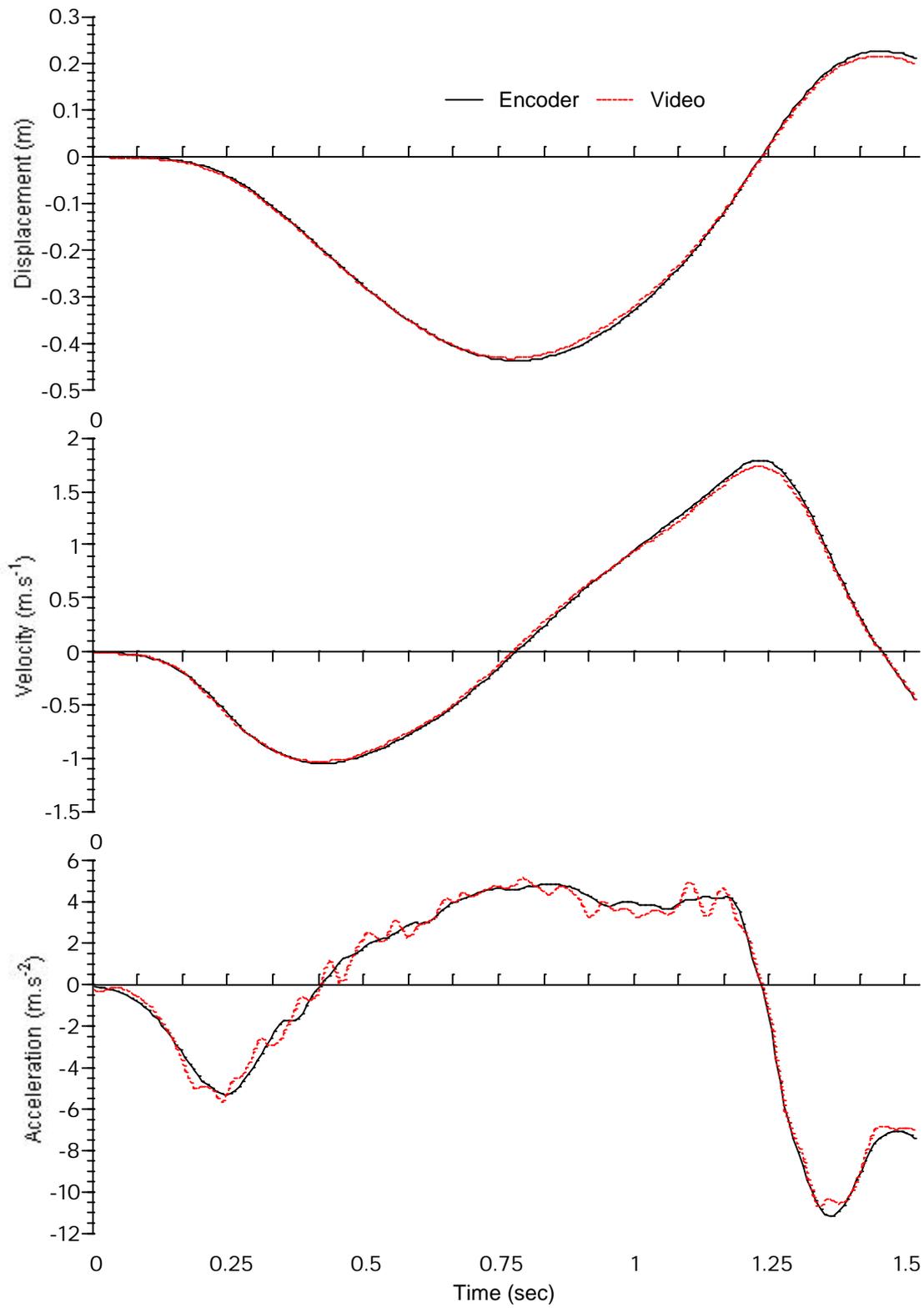
Displacement, velocity, and acceleration data from a representative trial are presented in Figure A.2. Comparisons of the summary variables of maxima, minima, and time between for displacement, velocity, and acceleration data appear in Table A.2. TEM% ranged from 0.26% for the time between maximum and minimum displacement, and minimum acceleration; up to 5.23% for measurement of the time between maximum and minimum acceleration. The ICC results varied considerably, ranging between 0.115 for minimum displacement up to 0.994 for measurement of the time between the maximum and minimum displacement.

**Table A.1** Accuracy and precision of distance measurement over 0.700 and 1.610 metres bar displacement for data pooled across all three trials.

Actual Bar Displacement	Measured Distance mean (s.d.) (metres)		Accuracy (%)		Precision (%)	
	Up	Down	Up	Down	Up	Down
0.700 m	0.7015(0.0019)	0.7016(0.0030)	0.22	0.22	0.26	0.44
1.610 m	1.6182(0.0016)	1.6176(0.0015)	0.51	0.47	0.10	0.09

### ***Experiment C***

Acceleration data for the ten trials on days 1 and 2 are presented in Table A4. The mean measured acceleration was  $9.713 \text{ m.s}^{-2}$  for day 1 and  $9.767 \text{ m.s}^{-2}$  for day 2 representing differences with the known value of 'g' of  $-1.0\%$  and  $-0.4\%$  respectively. The  $0.56\%$  difference between acceleration measured on days 1 and 2 was not statistically significant ( $t = -1.349$ ,  $p_{\text{two tailed}} = 0.210$ ). Inter-day TEM was  $0.081 \text{ m.s}^{-2}$  which equates to a TEM% of  $0.83\%$ .



**Figure A.2** Bar displacement, velocity and acceleration plotted against time based on data derived from a) rotary encoder system, and b) high speed video measurement system.

**Table A.2** Comparison of digital encoder and video systems for measurement of summary variables of bar kinematics during jump squats with light, medium, heavy loads.

Variable	Encoder	Video	Difference (%)	TEM	TEM% (%)	ICC
max. displacement	0.220	0.213	3.2	0.014	1.61	0.860
min. displacement	-0.432	-0.422	2.3	0.021	1.21	0.115
total displacement	0.652	0.635	2.6	0.035	1.36	0.453
time max to min	0.747	0.751	-0.5	0.0078	0.26	0.994
max. velocity	1.737	1.684	*3.1	0.11	1.66	0.778
min. velocity	-0.947	-0.935	1.3	0.03	0.67	0.922
time max to min	0.980	0.986	-0.6	0.013	0.33	0.992
max. acceleration	4.879	5.070	-3.9	0.404	2.03	0.831
min. acceleration	-10.783	-10.729	0.5	0.114	0.26	0.978
time max to min	0.345	0.313	9.3	0.069	5.23	0.582

\* indicates significant difference between encoder and video measures ( $p \leq 0.05$ ).

The results of comparing the displacement, velocity, and acceleration data derived from the encoder versus video systems at each time point throughout the movement are presented in Table A.3. Averaged across the three loads, the TEM was 0.0054 m, 0.022 m.s<sup>-1</sup>, and 0.41 m.s<sup>-2</sup>; and ICC was 0.845, 0.992, and 0.998 for displacement, velocity, and acceleration respectively.

**Table A.3** Comparison of the displacement, velocity, and acceleration data derived from the encoder versus video systems at each time point throughout the movement recorded at 120 Hz during jump squats with light, medium, heavy loads.

Load	Displacement		Velocity		Acceleration	
	TEM (m)	ICC	TEM (m.s <sup>-1</sup> )	ICC	TEM (m.s <sup>-2</sup> )	ICC
Light	0.0045	0.979	0.022	0.995	0.388	0.999
Medium	0.0053	0.907	0.024	0.990	0.44	0.999
Heavy	0.0065	0.648	0.019	0.991	0.42	0.996
Mean	0.0054	0.845	0.022	0.992	0.41	0.998

**Table A.4** Accuracy and precision of distance measurement over 0.700 and 1.610 metres bar displacement for data pooled across all three trials.

Trial	Day 1		Day 2	
	Measured Acceleration (m.s <sup>-2</sup> )	Error (%)	Measured Acceleration (m.s <sup>-2</sup> )	Error (%)
1	9.615	-2.0%	9.868	0.6%
2	9.634	-1.8%	9.789	-0.2%
3	9.76	-0.5%	9.823	0.1%
4	9.764	-0.5%	9.726	-0.9%
5	9.638	-1.8%	9.805	-0.1%
6	9.783	-0.3%	9.695	-1.2%
7	9.806	0.0%	9.908	1.0%
8	9.656	-1.6%	9.767	-0.4%
9	9.768	-0.4%	9.621	-1.9%
10	9.705	-1.1%	9.669	-1.4%
Mean	9.713	-1.0%	9.767	-0.4%
S.D.	0.072	0.73%	0.090	0.92%

## DISCUSSION

The aim of this study was to assess the validity and reliability of using a rotary digital encoder system to measure the kinematics of bar movement during a typical resistance training movement. Further, this system was compared with a high speed video system which has been traditionally used for such analyses. The system's ability to measure acceleration was assessed by comparing measurement of acceleration of a freely falling object with the known value of 'g'.

The encoder system could reliably measure bar displacement over the two distances tested. This was evident from the mean distances measured being approximately 1.5 mm and 8 mm different from the actual distances of 0.700 m and 1.610 m respectively (Table A.1). Accuracy and precision were also quite high being no worse than 0.5% with the majority of measures being 0.2% or better. These results are comparable to those reported for distance measurement using video. Shapiro, Blow, & Rash (1987) have reported an absolute mean error of 6.3 mm in measuring a distance of 2100 mm which is a precision of 0.3%. Similarly, Smith, Risenhoover, Cheetham & Scheirman (1989) determined mean errors of 5.8 mm for their video measurement system. A further evaluation of a video system for distance measurement reported mean errors of 2.8 mm in a 2 m field width (Newton & Neal, 1994).

The reliability of the encoder system in measuring the two test distances was very high. TEM, which reflects the measurement error of the system, was less than 1 mm and did not increase even when determined between measurements on different days. This consistency of measurement on repeat days is particularly notable and an important finding if the system is to be used for longitudinal testing of human performance. Further, the very high ICC of 0.9999 for both intra-day

and inter-day also attests to the very high reliability of this system in measuring displacement.

When completing a kinematic analysis of a weight lifting or resistance training movement, the biomechanist will generally examine variables which summarise the overall performance, for example peak velocity and acceleration. The encoder system produced results which were not significantly different from the video measures in all but maximum velocity. The TEM% and ICC measures (Tables 2 & 3) showed that there was some variation between the two systems, however, it is suggested that this variation was a result of inaccuracies in the video measurement system rather than the encoder system.

It is known that the process of differentiation magnifies any random errors in the displacement data (Winter, 1990). Examination of a representative trial (Figure A.2) reveals that although the displacement-time data collected from the two systems is very similar, the velocity, and in particular the acceleration-time data deviate much more for the video system. The acceleration-time data collected from the video system shows random noise about a relatively smooth curve produced from the encoder data. This random noise is the result of the video digitising process (Winter, 1990). Thus, it would appear that more accurate results in terms of velocity and acceleration measures could be obtained from an encoder measurement system rather than video for recording the kinematics of the load during resistance training.

Jump squats were used in this study because the movement involves relatively high displacement, velocity and acceleration values. It would be expected that similar results would be obtained for more traditional resistance training movements such as squat and bench press which involve slower velocities and much lower peak accelerations.

The system measured acceleration due to gravity with an error of 1.0% or less. Therefore, it can be concluded that the measurement of acceleration around 1g is accurate. Further, there was only 0.56% difference between measurement of 'g' on consecutive days indicating good repeatability in acceleration measurement inter-day. The low TEM and TEM% values comparing measurement on days 1 and 2 confirmed this. It was interesting that the system consistently tended to under-estimate the value of 'g'. Although it was not determined, it is suggested that the deficit was due to slight resistive forces in the measurement system. Sources of this resistance may include friction in the bearings and chains as well as rotary inertia in the sprockets and shafts of the PPS.

The Plyometric Power System as used in this study is a specialised piece of equipment which limits movement to a single plane. However, a digital encoder system could also be applied to other resistance testing and training devices, which incorporate a pulley system or involved

rotation about a central axis. The data produced from such a system would enhance performance testing and resistance training programs by providing 1) instantaneous feedback to the athlete or patient, and 2) automatic recording of repetitions, sets, volume, velocity, power, and work completed.

## **CONCLUSIONS**

Valid and reliable kinematic data can be derived from a digital rotary encoder interfaced with a counter timer card in a computer for measuring and recording human movements which maximise power production. This system is more accurate, precise and repeatable than using a high-speed video system for this purpose.

# ***Appendix B***

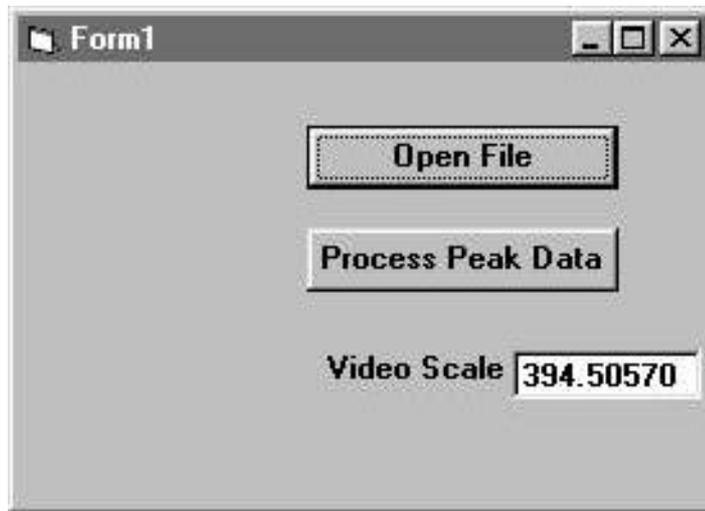
## **COMPUTER PROGRAMMES**

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A number of computer programmes were developed to operate the Plyometric Power System, record and analyse the data over the course of the five experiments conducted for this thesis. These programmes were written entirely by the author in the C and Visual Basic languages for both the MS-DOS and Windows 3.1 environments. Following is an overview of the software developed by the author for this thesis.

### **PLYOVID**

This programme was developed for data analysis in the validation study outlined in Appendix A. Bar displacement time data was recorded by the programme POWER from the encoder system as well as the video image being recorded on the high speed video system. Subsequently, the Peak Motion Measurement System was used to digitise the video recording and produce a data file of raw unscaled XY coordinates of the bar position. PLYOVID converted the displacement time data from the encoder system recorded at 500 Hz back to a 120 Hz data set using interpolation methods, scaled the data to real world distances, and stored the resulting data file. The programme also scaled the video XY coordinates to real world bar position and stored the data in a similar format file to the encoder data. Data files from both the video and encoder recording systems were then analysed by the PLYOASYS programme to calculate displacement, velocity, and acceleration variables.



**Figure B.1** Main window of the PLYOVID programme written in Visual Basic for data analysis in the validation experiment.

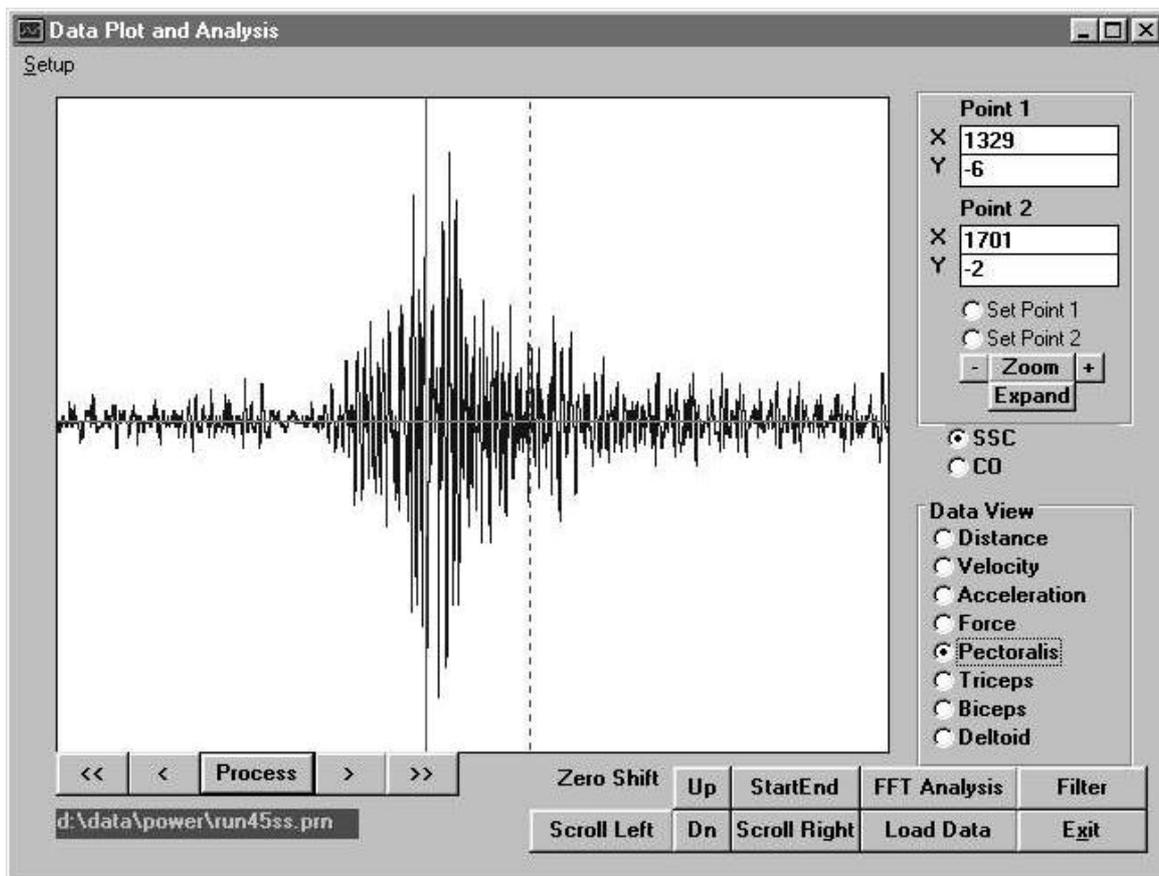
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## **POWER**

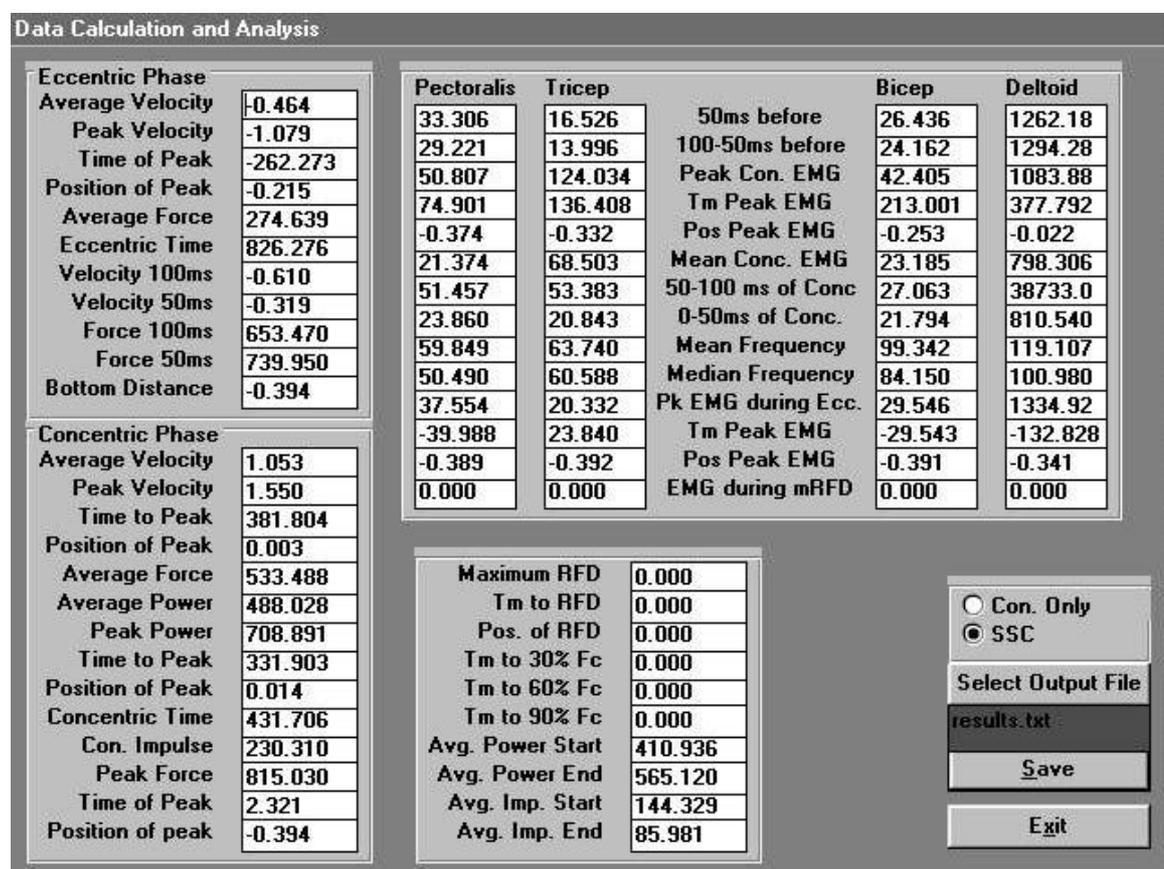
This programme was written in C using the Borland Turbo C Development System for the MS-DOS environment for use in Experiments One, Two, and Three. Data was collected via an analog to digital card and counter timer card installed in an 80386 based computer. Four channels of EMG data from the Quantec Electromyography System, three channels of force data from the Kistler Charge Amplifier, and bar position data from the encoder system of the Plyometric Power System were collected at 800 Hz, scaled based on previous calibration data, and then stored in data files for later analysis using the PLOT programme.

## **PLOT**

This programme was written in Visual Basic using the Microsoft Visual Basic Development System for the Windows 3.1 environment for use in Experiments One, Two, and Three. EMG data was rectified, integrated and normalised with respect to time. Mean and median frequency was calculated from the power spectrum using fast fourier transformation techniques. The bar position data was smoothed using a fourth-order Butterworth digital filter and then differentiated to produce velocity and acceleration data. Various measures of time, velocity, acceleration, force, rate of force development, and power were also calculated.



**Figure B.2** Main window of the PLOT programme written in Visual Basic for data analysis in Experiments One, Two, and Three.



**Figure B.3** Results window of the PLOT programme.

## PLYOPOW

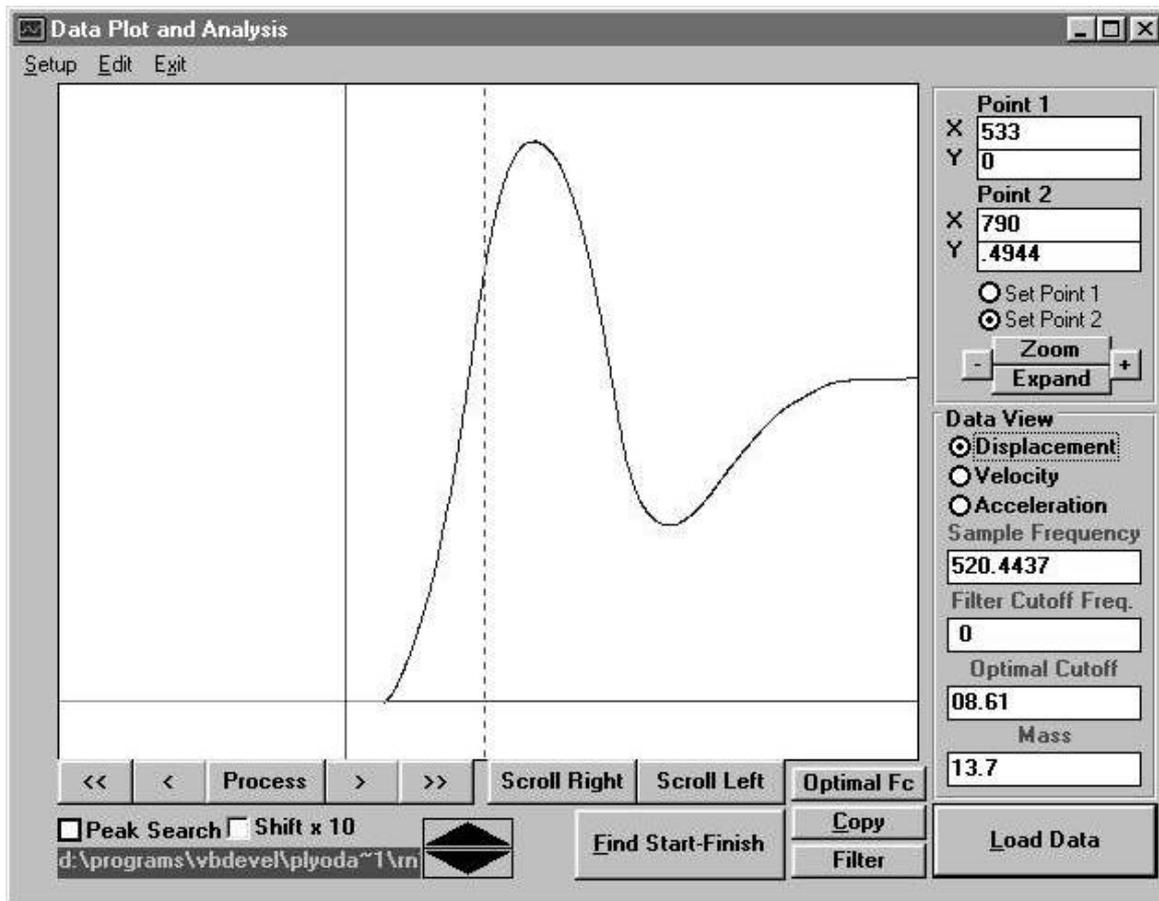
This programme was written in C using the Borland Turbo C Development System for the MS-DOS environment for use in Experiment Five. The programme was developed to operate the Plyometric Power System during subject training to record loads, distance, velocity, and power output. Auditory feedback on performance was provided via a sound card. The programme also controlled the electric brake system.



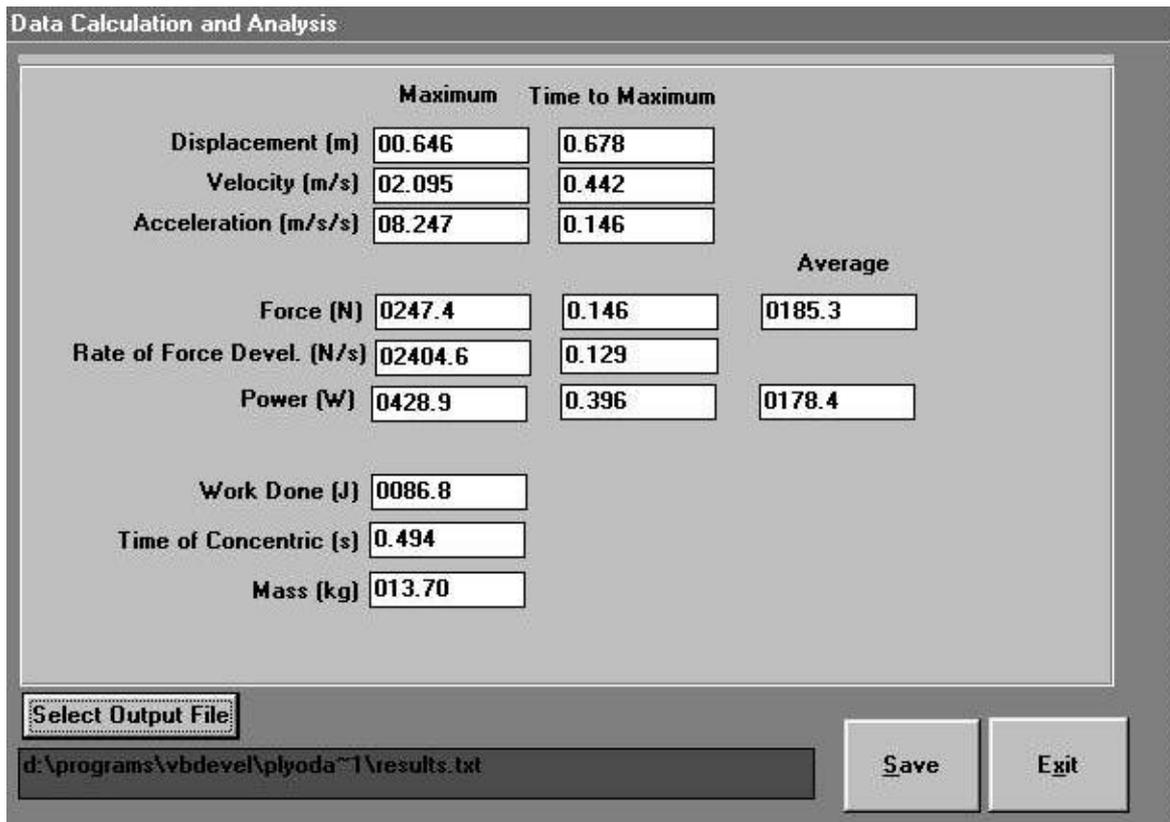
**Figure B.4** Main window of the programme PLYOPOW written in the C language and developed to operate the Plyometric Power System during the athlete training in Experiment Four.

## PLYOASYS

This programme was written in Visual Basic using the Microsoft Visual Basic Development System for the Windows 3.1 environment for use in Experiment Four. Bar displacement time data recorded from the encoder system was optimally smoothed using a fourth-order Butterworth digital filter. The optimal cut-off frequency was determined using the Jackson knee method (Jackson, 1979). The smoothed data was then differentiated to produce velocity and acceleration data which was combined with the known bar mass to calculate force, rate of force development and power output.



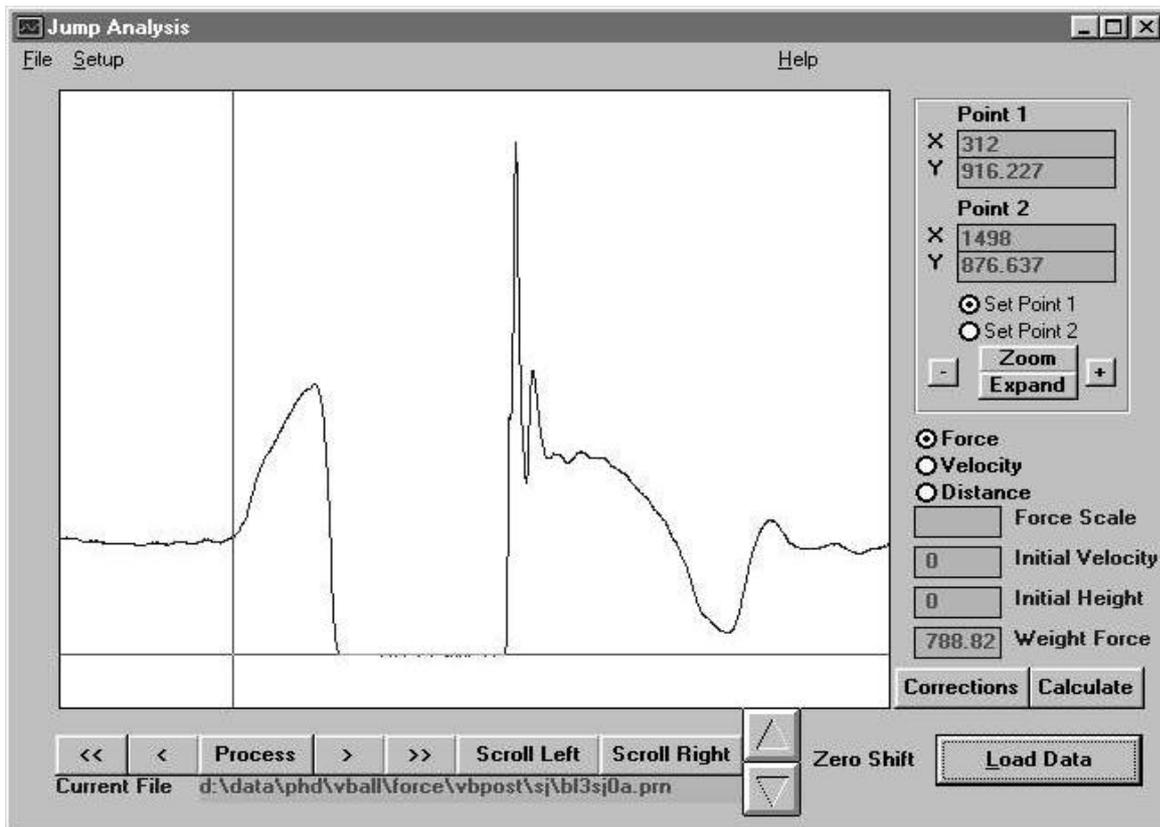
**Figure B.5** Main window of the PLYOASYS programme written in Visual Basic and developed to analyse the bar displacement data recorded by the encoder system of the Plyometric Power System during Experiment Four.



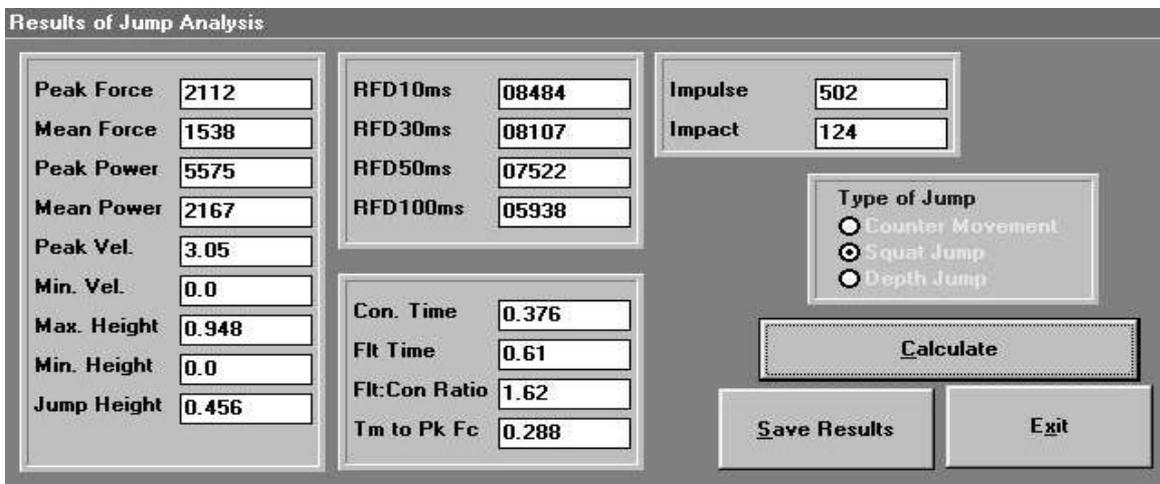
**Figure B.6** Results window of the PLYOASYS programme.

## JUMPASYS

This programme was written in Visual Basic using the Microsoft Visual Basic Development System for the Windows 3.1 environment for use in Experiment Four. Vertical ground reaction force collected from the AMTI forceplate system during the performance of various vertical jumps was integrated with time to produce velocity and displacement data. Subsequently, various measures of force, rate of force development, acceleration, velocity, displacement, impulse, impact and power output were calculated.



**Figure B.7** Main window of the JUMPASYS programme written in Visual Basic and developed to analyse the forceplate data collected during vertical jump testing in Experiment Four.



**Figure B.8** Results window of the JUMPASYS programme.

# ***Appendix C***

## **HUMAN ETHICS APPLICATION AND INFORMED CONSENT DOCUMENT FOR EXPERIMENT ONE**

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### **THE EFFECT OF A BRAKING DEVICE IN REDUCING THE GROUND IMPACT FORCES INHERENT IN MAXIMAL POWER TRAINING**

**Robert Newton, Ph.D student**

#### ***Aims or Purpose of the Experiment***

The purpose of this study was to investigate the effect of this braking mechanism on the impact forces associated with high intensity ballistic resistance training. Additionally, the effect of reducing the eccentric load on the subsequent concentric force production and performance was also assessed.

Methodology

#### **Subjects**

Subjects aged 17-25 years will be recruited from the university student population who are currently involved in a range of sports and activities (basketball, netball, football, athletics, aerobics) which require explosive-reactive leg movements. All subjects who volunteer will be fully informed as to the study and all of the risks associated with its participation and will know that they are free to withdraw from the study at any time without prejudice. Subsequently, written informed consent documents (attached) will be appropriately signed. A medical history questionnaire (attached) will be administered to assess past and present pathological conditions, orthopaedic problems, history of cardiovascular disorders, and current medication. Any subject with significant musculo-skeletal disorders, history of stroke or myocardial infarction, or who is taking medication likely to affect balance and/or muscle function will be excluded from the study. Twenty subjects will then be selected, consisting of 10 males and 10 females.

#### **Research Design**

The study will be cross-sectional in design and conducted in the Biomechanics laboratory at Southern Cross University. The subjects will be assessed while performing two types of vertical jump. Prior to testing a standard warm-up involving a 5 minute cycle at 60 rpm at a workload of 60 W will be performed on a Monark stationary bicycle. On completion of the cycle subjects will be instructed to perform a 3 minute standard stretching routine for the lower

body. Prior to data collection subjects will be familiarised with the testing equipment by performing a series of submaximal jumps with and without the braking mechanism engaged.

## **Experimental Tests**

On each test subjects will perform four successive jumps while being instructed and encouraged to jump for maximal height. Using a repeated measures design the sequence of presentation of both jump conditions will be randomised to control for order effects among subjects. The first group will initially perform the jumps with the brake mechanism engaged, followed by jumps without the braking system engaged. The second group will be tested in the reverse order to that of the first group. Between all repeat jumps a 3 to 5 minute recovery period will be imposed to negate any physiological effects of fatigue.

## **Force Measurement**

During each jump the vertical ground reaction forces will be measured using a forceplate mounted flush with the floor.

## **Informed Consent**

The subjects will be given a description of the study. If interested, each subject will be brought into the Centre where the project will be reviewed and the tests involved with associated risks detailed. The subject will be told that they can ask questions about the investigation at any time during their participation in the study. Any questions which the subjects may have will be answered by one of the investigators and telephone numbers provided if any other specific questions arise after the subject briefing. The subject will read the informed consent document. The investigator will then orally present the document to the interested subject to insure comprehension. Each subject will be asked if they understand what they are being asked to do and if they have any questions. If the subject is now ready to sign the informed consent document, he or she can do so at that time. If not, he or she can come back at another time to sign it. It will be made clear to each subject that they can withdraw at anytime from the investigation without prejudice.

## **Potential Risks and Methods to Reduce or Eliminate Risks to the Subjects**

The procedures and circumstances encompassed in this protocol provide for a high degree of safety. The performance of muscular exercise and physical effort can entail a certain degree of hazard for injury from overexertion and/or accident. This study will be planned to avoid injury to the musculoskeletal system. The possibility of cardiopulmonary overexertion is slight; it will be minimized by screening, selection, and monitoring procedures which are designed to anticipate and exclude the rare individual for whom exercise might be harmful. It is questionable whether it is possible to overexert the heart by voluntary exercise unless there is some underlying disease. Nevertheless, there are a number of disorders, some of which can readily escape clinical detection, where strenuous exercise may be potentially hazardous or may precipitate disability. Some of these, such as intracranial aneurysms or solitary pulmonary cysts or alveolar blebs, are rare and not readily diagnosed in the absence of symptoms; for these, a history of tolerance to prior strenuous exercise must suffice. Subjects in the age range specified are at very low risk of these problems. For other conditions which may be more common, such as ischemic heart disease, the striking age-related incidence and the association of several identifiable risk factors with latent disease provide a rationale for a directed screening of certain subject candidates. Every effort will be made to make this investigation safe for subject participation through subject familiarization, experienced personnel, warm-up and cool down (i.e., stretching and low intensity activity specific exercise), technique instruction and practice, supervision, screening, and monitoring while testing.

*Vertical Jump Tests:* The subjects in this test will be properly secured into the test position on the Plyometric Power System. The risks include delayed muscle soreness (24 to 72 hrs after exercise), pull or strain of a muscle, muscle spasm and, in extremely rare instances, muscle tears. These risks can be reduced or eliminated by close supervision during the test to insure that proper form and no jerking movements during a test are utilized and by having the subject properly positioned for each specific test. In addition, all subjects will be instructed to exert themselves only within the limits of pain and reasonable discomfort. The risk to the subject will also be reduced by having experienced personnel conduct each task.

## **Relevant Ethical Considerations**

All of the information gained from this study will be held in the strictest confidence. Any reports, papers, or oral presentation of the results will not include any information which could identify the subjects. All data will be filed under an identifying number. Only the principal investigator will have knowledge of the individual with whom the data corresponds. This consideration will be explained to all the subjects and the confidentiality of the testing assured.

**SOUTHERN CROSS UNIVERSITY**  
**CENTRE OF EXERCISE SCIENCE AND SPORT MANAGEMENT**  
**INFORMED CONSENT FORM**

Name of Project: **The effect of a braking device in reducing the ground impact forces inherent in maximal power training.**

You are invited to participate in a series of tests into the effects of a braking device on the ground impact experienced when landing from a vertical jump. We hope to establish the validity of this braking device for athletic training and rehabilitation. If you decide to participate, you will be tested for vertical jump performance under two conditions: 1) a normal jump with no braking; and 2) performing a vertical jump in a Plyometric Power System which will slow you speed of descent. Each test should take approximately 5 - 10 minutes to complete. Every effort will be made to minimise any reactions, such as pain, discomfort, weakness, or dizziness caused by the procedures and trained personnel will be in attendance to prevent any accident or hurt. In addition, 1 metre thick protective matting placed on the floor surrounding the testing area will protect you in the event of you losing your balance. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice.

If you have any questions, we expect you to ask us. If you have any additional questions later, Mr. Robert Newton, phone 203 234 will be happy to answer them. You will be given a copy of this form to keep.

***I have read the information above, and agree to participate in this study. I am over the age of 18 years.***

Name of Subject:  
.....

Signature of Subject: ..... Date: .....

Name of Witness (who shall be independent of the project)  
.....

Signature of the Witness: ..... Date: .....

I certify that the terms of the form have been verbally explained to the subject, that the subject appears to understand the terms prior to signing the form, and that proper arrangements have been made for an interpreter where English is not the subject's first language.

Signature of the researcher: ..... Date: .....

# ***Appendix D***

## **HUMAN ETHICS APPLICATION AND INFORMED CONSENT DOCUMENT FOR EXPERIMENT TWO**

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### **A COMPARISON OF THE TRADITIONAL AND BALLISTIC RESISTANCE TRAINING MOVEMENTS**

**Robert Newton, Ph.D student**

#### ***Aims or Purpose of the Experiment***

The purposes of this study are to 1) investigate the kinematics, kinetics and muscle activation when an athlete attempts to perform a traditional bench press in an explosive manner; and 2) compare the kinematics, kinetics and muscle activation during an explosive bench press with that of an explosive bench throw in which the athlete actually releases the load at the end of the motion in a ballistic manner.

#### ***Methodology***

#### **Subjects**

Male subjects aged 17-25 years will be recruited from the university student population who are not athletes but are recreationally weight training and do not report use of any anabolic drugs. All subjects will have been weight training for a minimum of six months and can bench press at least their own body weight. All subjects who volunteer will be fully informed as to the study and all of the risks associated with its participation and will know that they are free to withdraw from the study at any time without prejudice. Subsequently, written informed consent documents (attached) will be appropriately signed. A medical history questionnaire (attached) will be administered to assess past and present pathological conditions, orthopaedic problems, history of cardiovascular disorders, and current medication. Any subject with significant musculo-skeletal disorders, history of stroke or myocardial infarction, or who is taking medication likely to affect balance and/or muscle function will be excluded from the study. Seventeen subjects will then be selected.

#### **Research Design**

The study will be cross-sectional in design and conducted in the Biomechanics laboratory at Southern Cross University. Testing will be conducted over two sessions separated by four days.

## **Experimental Tests**

During the first testing session the subject's one repetition maximum (1RM) load for the bench press will be determined. The subject will then complete a number of bench throws using a load of 45% of 1RM to become familiar with the test movement. Each subject will be instructed to begin with the weighted barbell held at arms length, then lower the bar to the chest and immediately push it upwards attempting to project the bar for maximal height. The subjects have not performed explosive bench throws previously and as such, these throws will serve as familiarisation for the second testing session.

The second test session will begin with a general warmup involving two sets of 10 bench presses at a submaximal load of 45% of 1RM followed by 5 minutes of chest and triceps brachii static stretches. The subject will then be instructed to lie on the bench of the Plyometric Power System (PPS) such that the bar crosses the chest at the level of the nipples. To allow for comparison of EMG recorded during later trials, the subject will complete a single bench press with a load equal to his previously determined 1RM. Two movements will then be tested each using a load of 45% of the subject's previously determined 1RM: 1. An explosive bench press for which the subject will be instructed to lower the bar to the chest, "explode off the chest" as rapidly as possible and then stop the bar at arms length. The subject will support the bar in the hands at the completion of the typical bench press movement. 2. An explosive bench throw for which the subject will be instructed to lower the bar to the chest then "explode off the chest" as rapidly as possible, attempting to throw the bar for maximum height.

## **Force Measurement**

During each throw the vertical ground reaction forces will be measured using a forceplate mounted flush with the floor.

## **Electromyography**

During all throws each subject will have four silver/silver chloride surface electrode modules (Quantec, Brisbane, Australia) attached over the belly of the long head of triceps brachii, the anterior deltoid, the sternal portion of the pectoralis major, and the biceps brachii muscle. Before electrode application, each site will be shaved, cleansed with alcohol, gently abraded and a small amount of conductive gel applied to each electrode.

## **Informed Consent**

The subjects will be given a description of the study. If interested, each subject will be brought into the Centre where the project will be reviewed and the tests involved and associated risks detailed. The subject will be told that they can ask questions about the investigation at any time during their participation in the study. Any questions that the subjects may have will be answered by one of the investigators and telephone numbers provided if any other specific questions arise after the subject briefing. The subject will read the informed consent document. The investigator will then orally present the document to the interested subject to insure comprehension. Each subject will be asked if they understand what they are being asked to do and if they have any questions. If the subject is now ready to sign the informed consent document, he or she can do so at that time. If not, he or she can come back at another time to sign it. It will be made clear to each subject that they can withdraw at anytime from the investigation without prejudice.

## **Potential Risks and Methods to Reduce or Eliminate Risks to the Subjects**

The procedures and circumstances encompassed in this protocol provide for a high degree of safety. The performance of muscular exercise and physical effort can entail a certain degree of hazard for injury from overexertion and/or accident. This study will be planned to avoid injury to the musculoskeletal system. The possibility of cardiopulmonary overexertion is slight; it will be minimized by screening, selection, and monitoring procedures which are designed to anticipate and exclude the rare individual for whom exercise might be harmful. It is questionable whether it is possible to overexert the heart by voluntary exercise unless there is some underlying disease. Nevertheless, there are a number of disorders, some of which can readily escape clinical detection, where strenuous exercise may be potentially hazardous or may precipitate disability. Some of these, such as intracranial aneurysms or solitary pulmonary cysts or alveolar blebs, are rare and not readily diagnosed in the absence of symptoms; for these, a history of tolerance to prior strenuous exercise must suffice. Subjects in the age range specified are at very low risk of these problems. For other conditions which may be more common, such as ischemic heart disease, the striking age-related incidence and the association of several identifiable risk factors with latent disease provide a rationale for a directed screening of certain subject candidates. Every effort will be made to make this investigation safe for subject participation through subject familiarization, experienced personnel, warm-up and cool down (i.e., stretching and low intensity activity specific exercise), technique instruction and practice, supervision, screening, and monitoring while testing.

*Bench press and throw Tests:* The subjects in this test will be properly secured into the test position on the Plyometric Power System. The risks include delayed muscle soreness (24 to 72 hrs after exercise), pull or strain of a muscle, muscle spasm and, in extremely rare instances, muscle tears. These risks can be reduced or eliminated by close supervision during the test to insure that proper form and no jerking movements during a test are utilized and by having the subject properly positioned for each specific test. In addition, all subjects will be instructed to exert themselves only within the limits of pain and reasonable discomfort. The risk to the subject will also be reduced by having experienced personnel conduct each task. There is some risk of a skin reaction to the application of the EMG electrodes however this will be minimised by immediately cleansing the area after the tests are completed.

### **Relevant Ethical Considerations**

All of the information gained from this study will be held in the strictest confidence. Any reports, papers, or oral presentation of the results will not include any information which could identify the subjects. All data will be filed under an identifying number. Only the principal investigator will have knowledge of the individual with whom the data corresponds. This consideration will be explained to all the subjects and the confidentiality of the testing assured.

**SOUTHERN CROSS UNIVERSITY**  
**CENTRE OF EXERCISE SCIENCE AND SPORT MANAGEMENT**  
**INFORMED CONSENT FORM**

Name of Project: **A comparison of the traditional and ballistic resistance training movements.**

You are invited to participate in a series of tests which will compare the traditional bench press movement with an explosive bench throw movement. This experiment is a comparison of the muscle activation, bar movement and forces produced during each of these movements. If you decide to participate, you will be tested for: 1) maximum bench press strength (1RM); 2) explosive bench press using a load of 45% of 1RM; 3) explosive bench throw using a load of 45% of 1RM. Electrodes will be placed on your arms and chest during the testing to record the electrical activity of your muscles. Each test should take approximately 60 minutes to complete. Every effort will be made to minimise any reactions, such as pain, discomfort, weakness, or dizziness caused by the procedures and trained personnel will be in attendance to prevent any accident or hurt. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice.

If you have any questions, we expect you to ask us. If you have any additional questions later, Mr. Robert Newton, phone 203 234 will be happy to answer them. You will be given a copy of this form to keep.

*I have read the information above, and agree to participate in this study. I am over the age of 18 years.*

Name of Subject: .....

Signature of Subject: ..... Date: .....

Name of Witness (who shall be independent of the project) .....

Signature of the Witness: ..... Date: .....

I certify that the terms of the form have been verbally explained to the subject, that the subject appears to understand the terms prior to signing the form, and that proper arrangements have been made for an interpreter where English is not the subject's first language.

Signature of the researcher: ..... Date: .....

# ***Appendix E***

## **HUMAN ETHICS APPLICATION AND INFORMED CONSENT DOCUMENT FOR EXPERIMENT THREE**

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### **INFLUENCE OF LOAD AND STRETCH SHORTENING CYCLE ON THE KINEMATICS, KINETICS AND MUSCLE ACTIVATION DURING EXPLOSIVE UPPER BODY MOVEMENTS**

**Robert Newton, Ph.D Student**

#### ***Aims or Purpose of the Experiment***

The purposes of this study were to: 1) Investigate the effect of load on the velocity, force, power and muscle activity during maximal effort ballistic bench throws; 2) Assess the influence of the stretch shortening cycle on upper body explosive performance.

#### ***Methodology***

#### **Subjects**

Male subjects aged 17-25 years will be recruited from the university student population who are not athletes but are recreationally weight training and do not report use of any anabolic drugs. All subjects will have been weight training for a minimum of six months and can bench press at least their own body weight. All subjects who volunteer will be fully informed as to the study and all of the risks associated with its participation and will know that they are free to withdraw from the study at any time without prejudice. Subsequently, written informed consent documents (attached) will be appropriately signed. A medical history questionnaire (attached) will be administered to assess past and present pathological conditions, orthopaedic problems, history of cardiovascular disorders, and current medication. Any subject with significant musculo-skeletal disorders, history of stroke or myocardial infarction, or who is taking medication likely to affect balance and/or muscle function will be excluded from the study. Seventeen subjects will then be selected.

#### **Research Design**

The study will be cross-sectional in design and conducted in the Biomechanics laboratory at Southern Cross University. Testing will be conducted over two sessions separated by four days.

## **Experimental Tests**

During the first testing session the subject's one repetition maximum (1RM) load for the bench press will be determined. The subject will then complete a number of bench throws using a load of 45% of 1RM to become familiar with the test movement. Each subject will be instructed to begin with the weighted barbell held at arms length, then lower the bar to the chest and immediately push it upwards attempting to project the bar for maximal height. The subjects have not performed explosive bench throws previously and as such, these throws will serve as familiarisation for the second testing session.

The second test session will begin with a general warmup involving two sets of 10 bench presses at a submaximal load of 45% of 1RM followed by 5 minutes of chest and triceps brachii static stretches. The subject will then be instructed to lie on the bench of the Plyometric Power System (PPS) such that the bar crosses the chest at the level of the nipples. To allow for comparison of EMG recorded during later trials, the subject will complete a single bench press with a load equal to his previously determined 1RM. Two movements will then be tested each using a load of 45% of the subject's previously determined 1RM: 1. An explosive bench throw for which the subject will be instructed to lower the bar to the chest, wait 4 seconds and then "explode off the chest" as rapidly as possible, attempting to throw the bar for maximum height (concentric only throw). 2. An explosive bench throw for which the subject will be instructed to lower the bar to the chest then immediately "explode off the chest" as rapidly as possible, attempting to throw the bar for maximum height (stretch shortening cycle throw). Each throw will be repeated using loads of 15%, 30%, 45%, 60%, 75%, and 90% of the subject's previously determined 1RM.

## **Force Measurement**

During each throw the vertical ground reaction forces will be measured using a forceplate mounted flush with the floor.

## **Electromyography**

During all throws each subject will have four silver/silver chloride surface electrode modules (Quantec, Brisbane, Australia) attached over the belly of the long head of triceps brachii, the anterior deltoid, the sternal portion of the pectoralis major, and the biceps brachii muscle. Before electrode application, each site will be shaved, cleansed with alcohol, gently abraded and a small amount of conductive gel applied to each electrode.

## **Informed Consent**

The subjects will be given a description of the study. If interested, each subject will be brought into the Centre where the project will be reviewed and the tests involved and associated risks detailed. The subject will be told that they can ask questions about the investigation at any time during their participation in the study. Any questions that the subjects may have will be answered by one of the investigators and telephone numbers provided if any other specific questions arise after the subject briefing. The subject will read the informed consent document. The investigator will then orally present the document to the interested subject to insure comprehension. Each subject will be asked if they understand what they are being asked to do and if they have any questions. If the subject is now ready to sign the informed consent document, he or she can do so at that time. If not, he or she can come back at another time to sign it. It will be made clear to each subject that they can withdraw at anytime from the investigation without prejudice.

## **Potential Risks and Methods to Reduce or Eliminate Risks to the Subjects**

The procedures and circumstances encompassed in this protocol provide for a high degree of safety. The performance of muscular exercise and physical effort can entail a certain degree of hazard for injury from overexertion and/or accident. This study will be planned to avoid injury to the musculoskeletal system. The possibility of cardiopulmonary overexertion is slight; it will be minimized by screening, selection, and monitoring procedures which are designed to anticipate and exclude the rare individual for whom exercise might be harmful. It is questionable whether it is possible to overexert the heart by voluntary exercise unless there is some underlying disease. Nevertheless, there are a number of disorders, some of which can readily escape clinical detection, where strenuous exercise may be potentially hazardous or may precipitate disability. Some of these, such as intracranial aneurysms or solitary pulmonary cysts or alveolar blebs, are rare and not readily diagnosed in the absence of symptoms; for these, a history of tolerance to prior strenuous exercise must suffice. Subjects in the age range specified are at very low risk of these problems. For other conditions which may be more common, such as ischemic heart disease, the striking age-related incidence and the association of several identifiable risk factors with latent disease provide a rationale for a directed screening of certain subject candidates. Every effort will be made to make this investigation safe for subject participation through subject familiarization, experienced personnel, warm-up and cool down (i.e., stretching and low intensity activity specific exercise), technique instruction and practice, supervision, screening, and monitoring while testing.

*Bench Throw Tests:* The subjects in this test will be properly secured into the test position on the Plyometric Power System. The risks include delayed muscle soreness (24 to 72 hrs after exercise), pull or strain of a muscle, muscle spasm and, in extremely rare instances, muscle tears. These risks can be reduced or eliminated by close supervision during the test to insure that proper form and no jerking movements during a test are utilized and by having the subject properly positioned for each specific test. In addition, all subjects will be instructed to exert themselves only within the limits of pain and reasonable discomfort. The risk to the subject will also be reduced by having experienced personnel conduct each task. There is some risk of a skin reaction to the application of the EMG electrodes however this will be minimised by immediately cleansing the area after the tests are completed.

### **Relevant Ethical Considerations**

All of the information gained from this study will be held in the strictest confidence. Any reports, papers, or oral presentation of the results will not include any information which could identify the subjects. All data will be filed under an identifying number. Only the principal investigator will have knowledge of the individual with whom the data corresponds. This consideration will be explained to all the subjects and the confidentiality of the testing assured.

**SOUTHERN CROSS UNIVERSITY**  
**CENTRE OF EXERCISE SCIENCE AND SPORT MANAGEMENT**  
**INFORMED CONSENT FORM**

Name of Project: **Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation during explosive upper body movements.**

You are invited to participate in a series of tests which will examine the influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation during explosive upper body movements.

If you decide to participate, you will be tested for: 1) maximum bench press strength (1RM); 2) explosive bench throws using loads of 15%, 30%, 45%, 60%, 75%, and 90% of your previously determined 1RM. Electrodes will be placed on your arms and chest during the testing to record the electrical activity of your muscles. Each test should take approximately 60 minutes to complete. Every effort will be made to minimise any reactions, such as pain, discomfort, weakness, or dizziness caused by the procedures and trained personnel will be in attendance to prevent any accident or hurt.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice.

If you have any questions, we expect you to ask us. If you have any additional questions later, Mr. Robert Newton, phone 203 234 will be happy to answer them. You will be given a copy of this form to keep.

***I have read the information above, and agree to participate in this study. I am over the age of 18 years.***

Name of Subject: .....

Signature of Subject: ..... Date: .....

Name of Witness (who shall be independent of the project) .....

Signature of the Witness: ..... Date: .....

I certify that the terms of the form have been verbally explained to the subject, that the subject appears to understand the terms prior to signing the form, and that proper arrangements have been made for an interpreter where English is not the subject's first language.

Signature of the researcher: ..... Date: .....

# ***Appendix F***

## **HUMAN ETHICS APPLICATION AND INFORMED CONSENT DOCUMENT FOR EXPERIMENT FOUR**

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### **HUMAN USE APPLICATION**

THE PENNSYLVANIA STATE UNIVERSITY

#### ***Format for Procedures and Methodology Protection of Human Research Subjects***

***Study Title:*** Training vertical jump

***Investigators:*** Robert U. Newton, MHMS, William J. Kraemer, Ph.D., James M. Lynch, M.D.

#### **1. Brief Description of the Problem and the Purpose of the Investigation:**

The dominant requirement in sports involving explosive ballistic movements is power. Jumping in volleyball and basketball, rapid acceleration and change of direction in football and soccer, throwing in baseball and water polo, striking in racket sports; all require the muscles to develop high forces in a relatively short period of time and apply that force at fast movement speeds. By definition this performance quality is muscular power. The dilemma of contemporary coaching and training science is that little is known about the expression or development of muscular power. The sport science literature is dominated by studies into strength, despite the fact that power is the more important performance variable in both sporting and many occupational pursuits. One point of particular contention is what load to use when performing explosive power training. This study is designed to investigate the effect of heavy load versus light load training on explosive power performance.

#### **A. Background Discussion of the Problem**

The classic studies of Berger (1962) were a quest to determine the optimal load and repetition range for the maximisation of muscular strength. The results of this research are still pertinent to the strength training programs of today. Maximum strength however, lies to the far left of the concentric force velocity relationship. It is here one observes the development of high force and a required low velocity of movement. In practice, sport and ergonomic performance frequently involves rapid ballistic movement at a speed further along the movement velocity spectrum. This strength quality has been termed muscular power or speed strength and has been the subject of considerable research (Hakkinen & Komi, 1985; Kaneko, et al., 1983; Moritani, et al., 1987; Wilson et al., 1993; Young & Bilby, 1993).

There is however, some controversy over what load one should train with to best improve muscular power. Schmidtbleicher & Buehrle (1987) found loads of between 90% and 100% of maximum voluntary contraction to be

more effective than light loads of 45% of MVC for the development of movement speed and strength. Their results indicated that the heavy load training had a greater effect on the fast twitch fibers and that the 45% load had less of a training influence and affected both fast and slow twitch fibers.

However, the use of heavy loads would seem to contradict the velocity specific effects of resistance training that have been reported (Kaneko et al., 1983; Lesmes, 1970; Mofroid & Whipple, 1970). Heavy resistance strength training with high loads and slow contraction velocities has been shown to produce improvements predominantly in maximal strength i.e. in the high force region of the force-velocity curve (Ikai, 1970; Coyle et al., 1981; Hakkinen and Komi, 1985a). For faster contraction velocities the training effect is diminished (Hakkinen and Komi, 1985a) and as such, improvement in maximal mechanical power and dynamic performance in activities such as jumping is limited (Hakkinen & Komi, 1985a). Power type training, in which the load is less and the velocity of contraction is high, produces increases in force capability at higher contraction velocities with little or no improvement in maximum strength (Ikai, 1970; Coyle et al., 1981; Hakkinen & Komi, 1985b).

Kaneko et al. (1983) found that training with a load that maximised mechanical power (approx. 30% MVC) was more effective for increasing power than training with heavy loads (60% and 100% MVC) or without load (0% MVC). Thus there is an inherent conflict in training strategies between a) the perceived need to use high loads, high force and thus greater motor unit recruitment; and b) train at a speed which is similar to the competitive performance to maintain specificity.

## **2. Qualifications of the Investigators**

Dr. Kraemer is Director of Research for the Center for Sports Medicine and an Associate Professor of Applied Physiology at the Pennsylvania State University. Dr. Kraemer has been extensively involved with research in the study of exercise performance.

Mr. Newton is on twelve months sabbatical at Pennsylvania State University from Southern Cross University in Lismore, Australia. Mr. Newton is a Lecturer who has completed considerable research into human muscular strength and power.

Dr. Lynch is a team physician at the Center for Sports Medicine and has extensive experience working with athletes in their medical management and sports medicine care and will act as a co-investigator and medical monitor for this investigation

## **3. Subject Characteristics**

For the investigation we will recruit approximately twelve male and twelve female subjects with experience in weight training ranging in age from 18-25 years. All subjects will be informed of the procedures, risks, and benefits of the study following a medical screening by Dr. Lynch. They will provide written informed consent prior to participation.

## **4. Subject Sample and Recruitment**

Subjects will be recruited by flyers and contacted by word of mouth from the volleyball, basketball and track and field teams from The Pennsylvania State University. They will then be asked to participate after they are fully informed as to the study and all of the risks associated with its participation according to IRB guidelines (see #7). Subsequently, written informed consent documents will be appropriately signed. Subjects will be medically screened by Dr. Lynch and excluded clinically for pathological conditions, orthopaedic problems as well as any other history of cardiovascular disorders. Subjects will know that they are free to withdraw from the study at any time without prejudice.

## **5. Experimental Methods**

This investigation will take place in our clinical facility at the Medical Sciences Building. Subjects will complete medical and clinical history forms. Dr. Lynch, our team physician and a member of this experimental research team, will evaluate the medical history and examine each subject to insure safety of the subject and insure no prior or present disease state, musculoskeletal injury or disability will compromise their health or their physical performance with any of the testing. Any medical contraindication or concern will serve as a factor to exclude a subject from participation in this investigation.

Emergency phone, crash cart, drugs, and trained personnel will be available for all testing. We have found the need to conduct familiarization sessions with each test subject to eliminate any learning effects and maintain the high degree of test reliability. This will occur prior to the start of the testing.

The study proposed is as longitudinal training study with pre and post testing of the subject's performance.

### **Experimental Tasks**

**Part 1. Determination of one repetition maximum squat strength:** The subjects maximum half squat (1RM) will be determined according to the methods of Wilson, Elliott and Wood (1992). After an adequate general warm up and stretch, subjects will be given two warm up sets at comfortable sub-maximal loads using a squat movement on a "Smith Machine". Loads thereafter will be progressively increased, with 3 minutes rest provided between sets, until two failures occur at the same load. The final and heaviest weight lifted will be recorded in kilograms as their 1RM. This type of activity is similar to the weight training the subjects complete routinely.

**Part 2. Assessment of force and power output during vertical jump:** We will ask the subjects to complete a series of counter movement vertical jumps, both from the force plate and using a modified “Smith Machine”. These will be completed with loads of 0%, 15%, 30%, 45%, 60%, 75%, and 90% of his/her previously determined 1RM on a barbell carried on shoulders. In addition, depth jumps will be performed from the force plate, using drop heights of 0.25m, 0.50m, 0.75m and 1.0m. A 3 minute rest period will be imposed between each trial to allow adequate recovery of the ATP-CP energy system. The order of the different conditions will be randomised for each subject. During each trial, the computer will collect distance and time data from the Smith machine and force data from the force plate. We will also put surface electrodes on the muscles used in the bench press to evaluate muscle activity. Our medical instrumentation supervisors will evaluate the electrical hook-up. Surface EMG will not impart any electrical current into the subject.

**Part 3. Explosive power training:** The subjects will be randomly divided into two training groups. One group will train with a load of approximately 30% of his/her previously determined 1RM (light load). The other group will train with a load of approximately 90% of his/her previously determined 1RM. 1RM strength will be retested each week to maintain the same relative intensity. All subjects will complete a 10 minute warmup followed by 2 10 RM warmup sets. They will then complete 4 sets of explosive counter movement jumps on the Smith Machine using either the 30% 1RM or 90% 1RM load. The number of repetitions for each set will be adjusted to maintain the same total work for each training group. All subjects will train 3 times per week for 6 weeks. They will then swap training loads and train for a further 6 weeks.

At the conclusion of the training period, all subjects will be re-tested according to the procedures outlined in Parts 1 and 2.

**Data Analysis Techniques.** Displacement time data from the distance encoder will be filtered using a fourth order butterworth filter then differentiated to produce velocity-time and acceleration-time data. Force-time data will be derived from the force plate. The velocity data will be combined with the force data to calculate instantaneous power output. The following parameters will then be calculated:

1. Height thrown
2. Maximum force output
3. Time to maximum force output from the initiation of the upwards movement.
4. Total impulse calculated as the area under the force time curve.
5. Maximum rate of force development
6. Maximum instantaneous power output
7. Time to maximal power output from the initiation of the upwards movement
8. Average power output
9. Total work done calculated as the area under the power-time curve

for each load and drop height condition. This will allow assessment of each subject’s force and power capability across the concentric load-velocity spectrum.

**Statistical Analyses.** Means and standard errors will be calculated for the various data sets. Multivariate statistical analysis techniques will be used to evaluate the data resulting from this investigation. This would include analysis of variance with repeated measures and appropriate post-hoc comparisons to determine pairwise differences. Significance in this investigation will be set at  $p < 0.05$ . Computer analysis will be completed on IBM PC compatible computers using the SPSS for Windows Statistical Package.

## 6. Other Personnel

All of the following investigators (L. Perry Koziris, M.A., Jill Bush, B.S., Lisa Mangino, B.S., N. Travis Triplett, M.S., Brian G. Aguilera, B.S., Matt McCormick, B.S., Teo J. McCormick, B.S., R.D., Jeff Volek, B.S., Jeff McBride, B.S.) are graduate students in physiology and exercise physiology working with Dr. Kraemer. Each have been involved with many projects involving performance testing and have extensive experience in the Center for Sports Medicine in carrying out the tests that will be used this investigation. The research and medical staff in the Center for Sports Medicine will conduct this study.

All data will be kept in subject coded files in Dr. Kraemer’s locked office. When using the computer, a coded and locked program using subject’s codes on an IBM computer will be employed when statistical analyses are performed or when experimental feedback sheets for participants are produced. Each of the doctoral students have extensive experience in the testing being conducted in this study. All investigators and technicians are aware of the confidentiality involved with the proper conduct of such a study. Again, consistent with the conduct of human research studies, the data will be kept in locked confidential sites and not be available or divulged to anyone outside of the experimental research team who “need to know” for scientific purposes involved in carrying out this study. This will be made clear to each subject as well.

## 7. Informed Consent

The subjects will be given a description of the study. If interested, each subject will be brought to the Center where the project will be reviewed and the tests involved with associated risks detailed. The subject will be told that

they can ask questions about the investigation at any time during their participation in the study. Any questions that the subjects may have will be answered by one of the investigators and telephone numbers provided if any other specific questions arise after the subject briefing. The subject will read the informed consent document. The investigator will then orally present the document to the interested subject to ensure comprehension. Each subject will be asked if they understand what they are being asked to do and if they have any questions. If the subject is now ready to sign the informed consent document, he can do so at that time. If not, he can come back at another time to sign it. It will be made clear to each subject that they can withdraw at any time from the investigation without prejudice. It will also be made clear that a preliminary medical screening will be needed to be medically approved for the study. At that time, a medical screening test will be scheduled if the subject signs the informed consent document.

#### **8/9. Potential Risks and Methods to Reduce or Eliminate Risks to the Subjects**

The procedures and circumstances encompassed in this protocol provide for a high degree of safety. The performance of muscular exercise and physical effort can entail a certain degree of hazard for injury from overexertion and/or accident. This study will be planned to avoid injury to the musculoskeletal system. The possibility of cardiopulmonary overexertion is slight; it will be minimized by screening, selection, and monitoring procedures which are designed to anticipate and exclude the rare individual for whom exercise might be harmful. It is questionable whether it is possible to overexert the heart by voluntary exercise unless there is some underlying disease. Nevertheless, there are a number of disorders, some of which can readily escape clinical detection, where strenuous exercise may be potentially hazardous or may precipitate disability. Some of these, such as intracranial aneurysms or solitary pulmonary cysts or alveolar blebs, are rare and not readily diagnosed in the absence of symptoms; for these, a history of tolerance to prior strenuous exercise must suffice. For other conditions which may be more common, such as ischemic heart disease, the striking age-related incidence and the association of several identifiable risk factors with latent disease provide a rationale for a directed screening of certain subject candidates. Every effort will be made to make this investigation safe for subject participation through subject familiarization, experienced personnel, warm-up and cool down (i.e., stretching and low intensity activity specific exercise), technique instruction and practice, supervision, screening, and monitoring while testing.

**One Repetition Maximum Test.** The subjects in this test will be properly secured into the test position i.e. squatting under the bar. The risks include delayed muscle soreness (24 to 72 hrs after exercise), pull or strain of a muscle, muscle spasm and, in extremely rare instances, muscle tears. These risks can be reduced or eliminated by close supervision during the test to insure that proper form and no jerking movements during a test are utilized and by having the subject properly positioned for each specific test. In addition, as all subjects will be experienced in weight training they will be accustomed to such activities. The risk to the subject will also be reduced by having experienced personnel conduct each task.

**Electromyography Recording.** This test involves recording the electrical activity during the activation of the skeletal muscle. The risk associated with this procedure includes slight abrasion due to the skin preparation and possible skin inflammation due to a reaction to the electrode gel. Dr. Lynch will monitor the skin responses of each subject. High impedance amplifiers are used to record the electrical signal so current flow to the subject is extremely low. The amplifiers are totally isolated from the mains electrical supply negating the possibility of electrical shock.

**Loaded counter movement jumps and depth jumps.** The risks associated with such tests involve risks for muscle strain or pulls of the exercised musculature, delayed muscle soreness 24 to 48 hours after exercise, muscle spasm, and in extremely rare instances, muscle tears. Such risks are very rare and will be minimized or eliminated with proper instruction of the technique and proper warm-up prior to testing. In addition, the subjects will be experienced in weight training and thus their musculature has adapted to such stresses.

**Explosive jump training.** The training will be closely supervised and the level of overload will progress gradually. The risks associated with such training involve risks for muscle strain or pulls of the exercised musculature, delayed muscle soreness 24 to 48 hours after exercise, muscle spasm, and in extremely rare instances, muscle tears. Such risks are very rare and will be minimized or eliminated with proper instruction of the technique and proper warm-up prior to training. In addition, the subjects will be experienced in weight training and thus their musculature has adapted to such stresses.

#### **10. Benefits to the Individual Subjects Who Participate in the Study**

The principal benefit to the subjects will be an enhancement of vertical jumping ability which should improve performance in their chosen sport. Further benefits to the subject will be the information on their exercise performance abilities under the different testing conditions and other medical information gained from the medical screening. No other direct benefits will be achieved by the subject. All tests will be explained and interpreted for each subject and questions will be answered so that a maximum amount of educational understanding and use of the data will be achieved.

#### **11. Minimizing Potential Risks Throughout the Study**

As we have previously outlined, every attempt will be made to minimize any risks of testing over the course of this study. We will employ a close interaction with the physicians in this study. All of these factors, including those previously outlined, should all dramatically contribute to a reduction, if not an elimination, of any potential risks associated with this study.

**12. Experts in the Field if Counsel Needed**

Because our methods are so standard and very common techniques germane to the field of exercise physiology over the past 20 years, our methods can be evaluated by many of our colleagues in exercise physiology both on campus and off-campus (e.g., Olympic Training Center, Dr. Steve Fleck 719-578-4516).

## INFORMED CONSENT DOCUMENT

### Background for the Study

This is a study designed to investigate whether it is better to use light or heavy loads for the development of explosive muscle power in vertical jumping. There is considerable controversy as to whether athletes should train with a lighter load (30% of maximum strength) for which the speed of movement will be closer to the competitive event, or train with a heavy load (85%-95% of maximum strength). Depending upon your preference you can volunteer to be involved with the investigation if you want.

The purpose of the first part of the investigation will be to determine your maximum squat strength. This is required to determine the loads used in subsequent investigations. The purpose of the second part of the investigation will be to determine your strength, power output and muscle activation during vertical jumps with extra weight added to the body and also from drop heights up to 0.3m. The purpose of the third part of the investigation will be to train your vertical jump ability using weighted squat jumps. This will be conducted over a period of 8 weeks. You will then be retested as for part 2.

### Experimental Methods

The investigation will take place in the new Medical Sciences Building by Centre Community Hospital. Dr. Lynch, our team physician, will evaluate your medical history and examine you to insure no prior or present disease state, musculoskeletal injury or disability will compromise your health or your physical performance with any of the testing. Any medical contraindication or concern will serve as a factor to exclude you from participation in this investigation. Emergency phone, crash cart, drugs, and trained personnel will be available for all testing.

**Part 1. Determination of one repetition maximum squat strength:** We will determine your one repetition maximum squat strength. After an adequate general warm up and stretch, you will be given two warm up sets at comfortable sub-maximal loads using a half squat movement on a "Smith Machine". Loads thereafter will be progressively increased, with 3 minutes rest provided between sets, until two failures occur at the same load. The final and heaviest weight lifted will be recorded in kilograms as your 1RM.

**Part 2. Assessment of force and power output during vertical jump:** We will ask you to complete a series of counter movement vertical jumps, both from the force plate and using a modified "Smith Machine". These will be completed with loads of 0%, 15%, 30%, 45%, 60%, 75%, and 90% of your previously determined 1RM on a barbell carried on your shoulders. In addition, we will ask you to perform depth jumps from the force plate, using drop heights of 0.25m, 0.50m, 0.75m and 1.0m. A 3 minute rest period will be imposed between each trial to allow adequate recovery of the ATP-CP energy system. During each trial, the computer will collect distance and time data from the Smith machine and force data from the force plate. We will also put surface electrodes on your muscles used in the bench press to evaluate the activity of your muscles. Our medical instrumentation supervisors will evaluate the electrical hook-up. Surface EMG will not impart any electrical current to you.

**Part 3. Explosive power training:** You will be randomly assigned to one of two training groups. Depending on your group allocation you will train with a load of approximately 30% of your previously determined 1RM (light load) or with a load of approximately 90% of your previously determined 1RM. Your 1RM strength will be retested each week to maintain the same relative intensity. At the beginning of each training session you will complete a 10 minute warmup followed by 2 10 RM warmup sets. You will then complete 4 sets of explosive counter movement jumps on the Smith Machine using your assigned load. You will be asked to train 3 times per week for 6 weeks. You will then swap training loads and train for a further 6 weeks. At the conclusion of the training period, you will be re-tested according to the procedures outlined in Parts 1 and 2.

*One Repetition Maximum Test.* The risks associated with such a test include delayed muscle soreness (24 to 72 hrs after exercise), pull or strain of a muscle, muscle spasm and, in extremely rare instances, muscle tears. These risks can be reduced or eliminated by close supervision during the test to insure that proper form and no jerking movements during a test are utilized and by having you properly positioned for each specific test. In addition, as you are experienced in weight training you should be accustomed to such activities. The risk to you will also be reduced by having experienced personnel conduct each task.

*Electromyography Recording.* The risk associated with this procedure includes slight abrasion due to the skin preparation and possible skin inflammation due to a reaction to the electrode gel. High impedance amplifiers are used to record the electrical signal so current flow to your body is extremely low. The amplifiers are totally isolated from the mains electrical supply negating the possibility of electrical shock.

*Explosive jump training.* The risks associated with such tests involve risks for muscle strain or pulls of the exercised musculature, delayed muscle soreness 24 to 48 hours after exercise, muscle spasm, and in extremely rare instances, muscle tears. Such risks are very rare and will be minimized or eliminated with proper instruction of the technique and proper warm-up prior to testing. In addition, as you are experienced in weight training your musculature should be adapted to such stresses.

### Benefits to the Individual Subjects Who Participate in the Study

The principal benefit you will gain will be an enhancement of your vertical jumping ability which should improve performance in your chosen sport. The benefits to you will be the information on your exercise performance abilities under the different testing conditions and other medical information gained from the medical screening. No other

direct benefits will be achieved by you. All tests will be explained and interpreted for you and questions will be answered so that you can gain a maximum amount of educational understanding and use of your data.

All of the data collected, will be held in complete confidentiality and you will never be identified in any subsequent publications.

\_\_\_\_\_  
Test Subject Volunteer

\_\_\_\_\_  
Date

\_\_\_\_\_  
Witness

\_\_\_\_\_  
Date

\_\_\_\_\_  
Investigator

\_\_\_\_\_  
Date

# ***Appendix G***

## **HUMAN ETHICS APPLICATION AND INFORMED CONSENT DOCUMENT FOR EXPERIMENT FIVE**

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### **HUMAN USE APPLICATION**

THE PENNSYLVANIA STATE UNIVERSITY

#### ***Format for Procedures and Methodology Protection of Human Research Subjects***

***Study Title:*** Resistance training induced changes in muscle power in young and old men.

Investigators: Robert U. Newton, MHMS, William J. Kraemer, Ph.D., Keijo Hakkinen, Ph.D., James M. Lynch, M.D.

#### **1. Brief Description of the Problem and the Purpose of the Investigation:**

This study is designed to investigate the effect of heavy load versus light load training on explosive power performance.

##### **A. Background Discussion of the Problem**

Human muscle is composed of two broad categories of muscle cells (fibers). The slow twitch fiber is characterised by high endurance, but slow rate of force production and low power output. In contrast, the fast twitch fibers possess low endurance, but a fast rate of force production and high power output. Slow twitch fibers are innovated regularly by normal daily activity; however, the fast twitch fibers are used only during muscle contractions requiring high force or rapid movement. In the aged there is a selective disuse atrophy of the fast twitch fibers (Evans and Campbell, 1993; Lexell and Downham, 1992) which is most likely a result of physical activity levels which have declined to a chronically low intensity. This age-related muscle atrophy appears to be the result of a reduction in the size of individual fibers and/or a loss of individual fibers (Larsson et al., 1978; Aniansson et al., 1983; Lexell et al., 1988) and is associated with great decreases in muscle strength and power especially at the onset of the sixth decade both in men and women (Frontera et al., 1991; Häkkinen and Häkkinen 1991; Häkkinen et al., 1995, 1996). It has also been reported that age-related decreases in maximal power production take place actually to a greater degree than that of maximal muscle strength (Bosco and Komi 1980; Häkkinen and Häkkinen, 1991; Häkkinen et al., 1995, 1996). Faulkner et al. (1986) have demonstrated that the force per cross sectional area of Type I and Type II muscle fibers is similar however the peak power output of Type II fibers is fourfold that of Type I fibers. Therefore it is expected that a selective reduction in percentage of Type II fiber area will result in a considerable loss of power output with aging.

A loss of muscle power has been shown to have profound effects on functional activities such as speed of walking up stairs, standing up from a chair and gait speed (Bassey et al., 1992). Given that recovering balance after a trip or slip requires the application of a large amount of force in a short period of time, muscle power should be a significant factor in risk of falling (Evans & Campbell, 1993). This hypothesis is supported by previous research that demonstrates a clear relationship between maximal muscle power and a static balance test (Bassey et al., 1992).

There is a need for further research into the effects of aging on maximal power production and whether specific power training will be effective for slowing or even reversing the loss of fast twitch fiber area and number that occurs currently in our older people. Maximal power training may have a greater effect on functional capacity and the performance of daily activities than other more traditional methods such as heavy resistance exercise.

## 2. Qualifications of the Investigators

Mr. Newton is on twelve months sabbatical at Pennsylvania State University from Southern Cross University in Lismore, Australia. Mr. Newton is a Lecturer who has completed considerable research into human muscular strength and power.

Dr. Kraemer is Director of Research for the Center for Sports Medicine and an Associate Professor of Applied Physiology at the Pennsylvania State University. Dr. Kraemer has been extensively involved with research in the study of exercise performance.

Dr. Hakkinen is a visiting professor from the University of Jyväskylä in Finland and is considered a leading expert in the area of muscle strength and power.

Dr. Lynch is a team physician at the Center for Sports Medicine and has extensive experience working with athletes in their medical management and sports medicine care and will act as a co-investigator and medical monitor for this investigation

## 3. Subject Characteristics

For the investigation we will recruit approximately twelve young (age range of 20-30 years) and twelve older (age range of 60-70 years) subjects with no experience in weight training. All subjects will be informed of the procedures, risks, and benefits of the study following a medical screening by Dr. Lynch. They will provide written informed consent prior to participation.

## 4. Subject Sample and Recruitment

Subjects will be recruited by flyers and contacted by word of mouth from the local community around The Pennsylvania State University. They will then be asked to participate after they are fully informed as to the study and all of the risks associated with its participation according to IRB guidelines (see #7). Subsequently, written informed consent documents will be appropriately signed. Subjects will be medically screened by Dr. Lynch and excluded clinically for pathological conditions, orthopedic problems as well as any other history of cardiovascular disorders. Subjects will know that they are free to withdraw from the study at any time without prejudice.

## 5. Experimental Methods

This investigation will take place in our clinical facility at the Medical Sciences Building. Subjects will complete medical and clinical history forms. Dr. Lynch, our team physician and a member of this experimental research team, will evaluate the medical history and examine each subject to insure safety of the subject and insure no prior or present disease state, musculoskeletal injury or disability will compromise their health or their physical performance with any of the testing. Any medical contraindication or concern will serve as a factor to exclude a subject from participation in this investigation.

Emergency phone, crash cart, drugs, and trained personnel will be available for all testing. We have found the need to conduct familiarization sessions with each test subject to eliminate any learning effects and maintain the high degree of test reliability. This will occur prior to the start of the testing.

The study proposed is as longitudinal training study with pre and post testing of the subject's performance.

### Experimental Tests

**Test 1. Determination of one repetition maximum squat strength:** The subjects maximum half squat (1RM) will be determined according to the methods of Wilson, Elliott and Wood (1992). After an adequate general warm up and stretch, subjects will be given two warm up sets at comfortable sub-maximal loads using a squat movement on a "Smith Machine". Loads thereafter will be progressively increased, with 3 minutes rest provided between sets, until two failures occur at the same load. The final and heaviest weight lifted will be recorded in kilograms as their 1RM. This type of activity is similar to the weight training the subjects complete routinely.

**Test 2. Assessment of maximal power performance in the jump squat:** The subject's maximum squat jump performance will be determined according to the methods of Wilson et al. (1993). After an adequate general warm up and stretch, subjects will be given two warm up sets at comfortable sub-maximal loads using a squat movement on a "Smith Machine". The subjects will then perform three jump squats at each load of bar weight (17 kg), 30% and 60% or their previously determined 1RM.

**Test 3. Assessment of isometric rate of force development:** Maximal isometric force, and maximal rate of isometric force development (RFD) in the force-time curve in the squat position will be measured using the Plyometric Power System. In this test the subjects will assume a squatting position so that the knee and hip angles are 90 and 110 degrees, respectively. The force output will be recorded using resistive force transducers in series (Entran) with a chain securing a bar positioned across the subject's shoulders. The subjects will be instructed to exert their maximal force as fast as possible during a period of 2.5 - 5.0 s. Three to four maximal trials will be completed for each subject until no further increases in peak force are produced.

**Test 4. Recording of surface electromyography:** Electromyographic (EMG) activity during the isometric squat and jump squats will be recorded from the vastus lateralis (VL) and vastus medialis (VM) of the right and left leg. Two active silver/silver chloride surface EMG electrodes (pre-gelled, disposable) separated by 2 cm will be attached to the belly of each muscle on the approximate position of the motor point area determined using anatomical landmarks, and a third ground electrode will be attached to the lateral malleolus. Before electrode application each site will be shaved, cleansed with alcohol and gently abraded.

### **Resistance training**

The subjects will participate three times a week in a supervised strength training program for ten weeks. Each training session will include the squat, knee extension, knee flexion exercise on the machines, trunk extension and trunk flexion exercises using free weights and/or bench press or calf raise exercises on the machines. During each week, the days will be broken into a "hypertrophy day", a "strength day" and a "power day". One session of the week the subjects will perform 8-10 RM sets, another session 3-5 RM sets and for the third session the subjects will perform the squat and the knee extension exercises with lower loads but these exercises will be completed as explosively as possible for 6-8 reps per set. All the exercises will be performed using concentric muscle actions followed by eccentric actions during the "lowering" phase of the movement. Each session the subjects will perform 3-6 sets of each exercise. The volume of the training will increase progressively throughout the 10-week training, a so-called periodized program.

At the conclusion of the training period, all subjects will be re-tested according to the procedures outlined in the Experimental Tests.

**Statistical Analyses.** Means and standard errors will be calculated for the various data sets. Multivariate statistical analysis techniques will be used to evaluate the data resulting from this investigation. This would include analysis of variance with repeated measures and appropriate post-hoc comparisons to determine pairwise differences. Significance in this investigation will be set at  $p < 0.05$ . Computer analysis will be completed on IBM PC compatible computers using the SPSS for Windows Statistical Package.

### **6. Other Personnel**

All of the following investigators (L. Perry Koziris, M.A., Jill Bush, B.S., Lisa Mangino, B.S., N. Travis Triplett, M.S., Brian G. Aguilera, B.S., Matt McCormick, B.S., Teo J. McCormick, B.S., R.D., Jeff Volek, B.S., Jeff McBride, B.S.) are graduate students in physiology and exercise physiology working with Dr. Kraemer. Each have been involved with many projects involving performance testing and have extensive experience in the Center for Sports Medicine in carrying out the tests that will be used in this investigation. The research and medical staff in the Center for Sports Medicine will conduct this study.

All data will be kept in subject coded files in Dr. Kraemer's locked office. When using the computer, a coded and locked program using subject's codes on an IBM computer will be employed when statistical analyses are performed or when experimental feedback sheets for participants are produced. Each of the doctoral students has extensive experience in the testing being conducted in this study. All investigators and technicians are aware of the confidentiality involved with the proper conduct of such a study. Again, consistent with the conduct of human research studies, the data will be kept in locked confidential sites and not be available or divulged to anyone outside of the experimental research team who "need to know" for scientific purposes involved in carrying out this study. This will be made clear to each subject as well.

### **7. Informed Consent**

The subjects will be given a description of the study. If interested, each subject will be brought to the Center where the project will be reviewed and the tests involved with associated risks detailed. The subject will be told that they can ask questions about the investigation at any time during their participation in the study. Any questions that the subjects may have will be answered by one of the investigators and telephone numbers provided if any other specific questions arise after the subject briefing. The subject will read the informed consent document. The investigator will then orally present the document to the interested subject to ensure comprehension. Each subject will be asked if they understand what they are being asked to do and if they have any questions. If the subject is now ready to sign the informed consent document, he can do so at that time. If not, he can come back at another time to sign it. It will be made clear to each subject that they can withdraw at any time from the investigation without prejudice. It will also be

made clear that a preliminary medical screening will be needed to be medically approved for the study. At that time, a medical screening test will be scheduled if the subject signs the informed consent document.

### **8/9. Potential Risks and Methods to Reduce or Eliminate Risks to the Subjects**

The procedures and circumstances encompassed in this protocol provide for a high degree of safety. The performance of muscular exercise and physical effort can entail a certain degree of hazard for injury from overexertion and/or accident. This study will be planned to avoid injury to the musculoskeletal system. The possibility of cardiopulmonary overexertion is slight; it will be minimized by screening, selection, and monitoring procedures that are designed to anticipate and exclude the rare individual for whom exercise might be harmful. It is questionable whether it is possible to overexert the heart by voluntary exercise unless there is some underlying disease. Nevertheless, there are a number of disorders, some of which can readily escape clinical detection, where strenuous exercise may be potentially hazardous or may precipitate disability. Some of these, such as intracranial aneurysms or solitary pulmonary cysts or alveolar blebs, are rare and not readily diagnosed in the absence of symptoms; for these, a history of tolerance to prior strenuous exercise must suffice. For other conditions which may be more common, such as ischemic heart disease, the striking age-related incidence and the association of several identifiable risk factors with latent disease provide a rationale for a directed screening of certain subject candidates. Every effort will be made to make this investigation safe for subject participation through subject familiarization, experienced personnel, warm-up and cool down (i.e., stretching and low intensity activity specific exercise), technique instruction and practice, supervision, screening, and monitoring while testing.

**One Repetition Maximum Test.** The subjects in this test will be properly secured into the test position i.e. squatting under the bar. The risks include delayed muscle soreness (24 to 72 hrs after exercise), pull or strain of a muscle, muscle spasm and, in extremely rare instances, muscle tears. These risks can be reduced or eliminated by close supervision during the test to insure that proper form and no jerking movements during a test are utilized and by having the subject properly positioned for each specific test. The risk to the subject will also be reduced by having experienced personnel conduct each task.

**Isometric squat test.** The subjects in this test will be properly secured into the test position i.e. squatting under the bar. The risks include delayed muscle soreness (24 to 72 hrs after exercise), pull or strain of a muscle, muscle spasm and, in extremely rare instances, muscle tears. These risks can be reduced or eliminated by close supervision during the test to insure that proper form and no jerking movements during a test are utilized and by having the subject properly positioned for each specific test. The risk to the subject will also be reduced by having experienced personnel conduct each task.

**Electromyography Recording.** This test involves recording the electrical activity during the activation of the skeletal muscle. The risk associated with this procedure includes slight abrasion due to the skin preparation and possible skin inflammation due to a reaction to the electrode gel. Dr. Lynch will monitor the skin responses of each subject. High impedance amplifiers are used to record the electrical signal so current flow to the subject is extremely low. The amplifiers are totally isolated from the mains electrical supply negating the possibility of electrical shock.

**Loaded squat jumps.** The risks associated with such tests involve risks for muscle strain or pulls of the exercised musculature, delayed muscle soreness 24 to 48 hours after exercise, muscle spasm, and in extremely rare instances, muscle tears. Such risks are very rare and will be minimized or eliminated with proper instruction of the technique and proper warm-up prior to testing.

**Resistance training.** The training will be closely supervised and the level of overload will progress gradually. The risks associated with such training involve risks for muscle strain or pulls of the exercised musculature, delayed muscle soreness 24 to 48 hours after exercise, muscle spasm, and in extremely rare instances, muscle tears. Such risks are very rare and will be minimized or eliminated with proper instruction of the technique and proper warm-up prior to training.

### **10. Benefits to the Individual Subjects Who Participate in the Study**

The principal benefit to the subjects will be an enhancement of muscle strength, increased muscle size, and improved muscle power output which should improve their capability for performing daily activities. Further benefits to the subject will be the information on their exercise performance abilities under the different testing conditions and other medical information gained from the medical screening. No other direct benefits will be achieved by the subject. All tests will be explained and interpreted for each subject and questions will be answered so that a maximum amount of educational understanding and use of the data will be achieved.

### **11. Minimizing Potential Risks Throughout the Study**

As we have previously outlined, every attempt will be made to minimize any risks of testing over the course of this study. We will employ a close interaction with the physicians in this study. All of these factors, including those

previously outlined, should all dramatically contribute to a reduction, if not an elimination, of any potential risks associated with this study.

#### **12. Experts in the Field if Counsel Needed**

Because our methods are so standard and very common techniques germane to the field of exercise physiology over the past 20 years, our methods can be evaluated by many of our colleagues in exercise physiology both on campus and off-campus (e.g., Olympic Training Center, Dr. Steve Fleck 719-578-4516).

## INFORMED CONSENT DOCUMENT

### Background for the Study

Human muscle is composed of two broad categories of muscle cells (fibers). The slow twitch fiber is characterised by high endurance, but slow rate of force production and low power output. In contrast, the fast twitch fibers possess low endurance, but a fast rate of force production and high power output. Slow twitch fibers are innovated regularly by normal daily activity; however, the fast twitch fibers are used only during muscle contractions requiring high force or rapid movement. In the aged there is a selective disuse atrophy of the fast twitch fibers (Evans and Campbell, 1993; Lexell and Downham, 1992) which is most likely a result of physical activity levels which have declined to a chronically low intensity. This age-related muscle atrophy appears to be the result of a reduction in the size of individual fibers and/or a loss of individual fibers (Larsson et al., 1978; Aniansson et al., 1983; Lexell et al., 1988) and is associated with great decreases in muscle strength and power especially at the onset of the sixth decade both in men and women (Frontera et al., 1991; Häkkinen and Häkkinen 1991; Häkkinen et al., 1995, 1996). It has also been reported that age-related decreases in maximal power production take place actually to a greater degree than that of maximal muscle strength (Bosco and Komi 1980; Häkkinen and Häkkinen, 1991; Häkkinen et al., 1995, 1996). Faulkner et al. (1986) have demonstrated that the force per cross sectional area of Type I and Type II muscle fibers is similar however the peak power output of Type II fibers is fourfold that of Type I fibers. Therefore it is expected that a selective reduction in percentage of Type II fiber area will result in a considerable loss of power output with aging. A loss of muscle power has been shown to have profound effects on functional activities such as speed of walking up stairs, standing up from a chair and gait speed (Bassey et al., 1992). Given that recovering balance after a trip or slip requires the application of a large amount of force in a short period of time, muscle power should be a significant factor in risk of falling (Evans & Campbell, 1993). This hypothesis is supported by previous research that demonstrates a clear relationship between maximal muscle power and a static balance test (Bassey et al., 1992).

There is a need for further research into the effects of aging on maximal power production and whether specific power training will be effective for slowing or even reversing the loss of fast twitch fiber area and number that occurs currently in our older people. Maximal power training may have a greater effect on functional capacity and the performance of daily activities than other more traditional methods such as heavy resistance exercise.

The purpose of the first part of the investigation will be to determine your maximum squat strength, isometric squat strength and maximal power capacity. You will then undergo a resistance training program for a period of 10 weeks after which time you will be retested.

### Experimental Methods

The investigation will take place in the new Medical Sciences Building by Centre Community Hospital. Dr. Lynch, our team physician, will evaluate your medical history and examine you to insure no prior or present disease state, musculoskeletal injury or disability will compromise your health or your physical performance with any of the testing. Any medical contraindication or concern will serve as a factor to exclude you from participation in this investigation. Emergency phone, crash cart, drugs, and trained personnel will be available for all testing.

**Test 1. Determination of one repetition maximum squat strength:** We will determine your one repetition maximum squat strength. After an adequate general warm up and stretch, you will be given two warm up sets at comfortable sub-maximal loads using a half squat movement on a "Smith Machine". Loads thereafter will be progressively increased, with 3 minutes rest provided between sets, until two failures occur at the same load. The final and heaviest weight lifted will be recorded in kilograms as your 1RM.

**Test 2. Assessment of squat jump performance:** We will ask you to complete a series of counter movement vertical jumps using a modified "Smith Machine". These will be completed with loads of 17 kg, 30% and 60% of your previously determined 1RM on a barbell carried on your shoulders. A 3 minute rest period will be imposed between each trial to allow adequate recovery of the ATP-CP energy system. During each trial, the computer will collect distance and time data from the Smith machine. We will also put surface electrodes on your muscles used in the squat to evaluate the activity of your muscles. Our medical instrumentation supervisors will evaluate the electrical hook-up. Surface EMG will not impart any electrical current to you.

**Resistance training:** You will complete a 10 week supervised resistance training program consisting of 3 sessions per week.

*One Repetition Maximum Test, Isometric Squat Test and Squat Jump Test.* The risks associated with such tests include delayed muscle soreness (24 to 72 hrs after exercise), pull or strain of a muscle, muscle spasm and, in extremely rare instances, muscle tears. These risks can be reduced or eliminated by close supervision during the test to insure that proper form and no jerking movements during a test are utilized and by having you properly positioned for each specific test. The risk to the you will also be reduced by having experienced personnel conduct each task.

*Electromyography Recording.* The risk associated with this procedure includes slight abrasion due to the skin preparation and possible skin inflammation due to a reaction to the electrode gel. High impedance amplifiers are used to record the electrical signal so current flow to your body is extremely low. The amplifiers are totally isolated from the mains electrical supply negating the possibility of electrical shock.

*Resistance training.* The risks associated with such training involve risks for muscle strain or pulls of the exercised musculature, delayed muscle soreness 24 to 48 hours after exercise, muscle spasm, and in extremely rare instances,

muscle tears. Such risks are very rare and will be minimized or eliminated with proper instruction of the technique and proper warm-up prior to testing.

#### Benefits to the Individual Subjects Who Participate in the Study

The principal benefit to you will be an enhancement of muscle strength, increased muscle size, and improved muscle power output which should improve your capability for performing daily activities. Further benefits to you will be the information on your exercise performance abilities under the different testing conditions and other medical information gained from the medical screening. No other direct benefits will be achieved by you. All tests will be explained and interpreted and questions will be answered so that a maximum amount of educational understanding and use of the data will be achieved.

All of the data collected, will be held in complete confidentiality and you will never be identified in any subsequent publications.

\_\_\_\_\_  
Test Subject Volunteer

\_\_\_\_\_  
Date

\_\_\_\_\_  
Witness

\_\_\_\_\_  
Date

\_\_\_\_\_  
Investigator

\_\_\_\_\_  
Date

# Appendix H

## MEDICAL HISTORY QUESTIONNAIRE

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CENTRE OF EXERCISE SCIENCE AND SPORT MANAGEMENT

CONFIDENTIAL

MEDICAL HISTORY QUESTIONNAIRE

(to be filled in and returned prior to testing)

All information will be treated as confidential and will not be released or used for any purpose other than this study without the subject's prior consent. The data used for scientific experimentation will be done with anonymity.

Surname:.....Given Names:.....

Address:.....Post Code:.....

Date of Birth:.....Telephone: (wk).....(hm).....

Sex: M / F (please circle)

Doctor's Name:.....Address:.....

..... Postcode:.....

Telephone:.....

Contact Person:.....Telephone:.....

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### Medical History

Present medical complaints

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Are you taking any prescribed medicines?.....

Any major illnesses in the past?.....

Any hospitalisation or operations?.....

Do you suffer from high blood pressure?.....

Have you ever had a stroke?.....

Have you ever been diagnosed as having cardiovascular disease?.....

Are you currently suffering any illness e.g. infection, injury? .....

Have you ever had the following: Tick if Yes ( ). Give details in the spaces provided.

- ( ) Family history of heart disease (heart attack, atherosclerosis, bypass surgery, etc.
- ( ) Family history of stroke of relatives under the age of 65 years.
- ( ) Asthma or other breathing problems.
- ( ) Arthritis
- ( ) A Hernia
- ( ) Diabetes
- ( ) Back complaint
- ( ) Epilepsy or fits
- ( ) Muscular pain or cramps
- ( ) Are you, or is there any risk that you may be pregnant?
- ( ) Absent or irregular menstrual periods
- ( ) Any other difficulties associated with exercise or weight training?
- ( ) Blackouts/fainting attacks
- ( ) Giddiness
- ( ) Bone or joint problems
- ( ) Gout
- ( ) Osteoporosis

Details:

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#### PHYSICAL ACTIVITY QUESTIONNAIRE

Have you participated in organised sports or a program of regular exercise during the past year? If yes, please specify the type of activity and number of hours per week.

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Are you currently involved in physical activity? If yes, please specify the type of activity and how many hours per week.

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# ***Appendix I***

## **DETERMINATION OF STATISTICAL POWER**

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### **Experiment One**

Previous experience with the braking system suggested that a large effect size (ES) could be expected in terms of peak impact force and impact impulse. Based on this knowledge an ES of 1.0 was used in subsequent power calculations. In this experiment the researcher wanted to be 90% (power = 0.9, Beta = 1 - 0.9 = 0.1) confident that such a difference in the dependent variables between the two techniques would be detected (ie. The null hypothesis would be rejected). Therefore at an alpha level of 0.05 (one-tailed test) the sample size required was found to be 20 subjects resulting in a power of 0.93 (Cohen, 1988: Table 2.3.2).

### **Experiment Two**

Pilot research suggested that an ES of at least 1.2 could be expected in terms of the velocity, force and power measures and this value was used in subsequent statistical power calculations. In this experiment the researcher wanted to be 90% (power = 0.9, Beta = 1 - 0.9 = 0.1) confident that such a difference in the dependent variables between the two techniques would be detected (ie. The null hypothesis would be rejected). Therefore at an alpha level of 0.05 (one-tailed test) the sample size required was found to be 15 subjects resulting in a power of 0.94 (Cohen, 1988: Table 2.3.2).

## Experiment Three

Pilot research suggested that an ES of at least 1.0 could be expected in terms of the velocity, force and power measures and this value was used in subsequent statistical power calculations. In this experiment the researcher wanted to be 90% (power = 0.9, Beta = 1 - 0.9 = 0.1) confident that such a difference in the dependent variables between the concentric only and stretch shortening cycle throws would be detected (ie. The null hypothesis would be rejected). Therefore at an alpha level of 0.05 (one-tailed test) the sample size required was found to be 17 subjects resulting in a power of 0.89 (Cohen, 1988: Table 2.3.2).

## Experiment Four

The principle criteria for differentiating the control and treatment groups in this study was the standing jump and reach (SJR) and 3-step approach jump and reach (AJR) performances. Based on the results reported by Wilson et al. (1993) and accounting for the fact that the subjects in the current study were already elite athletes, it was anticipated to produce a 7% improvement in vertical jump. A 7% improvement would also be considered meaningful given the training background of the subjects.

Examination of prior test histories for past players revealed that the average SJR was 67 cm with an SD of 4.5 cm. Therefore, if a 7% increase is projected the ES can be calculated as follows:

$$ES = \frac{m_B - m_A}{s}$$
$$ES = \frac{1.07 \times 67 - 67}{4.5}$$
$$ES = 1.02$$

Examination of prior test histories for past players revealed that the average AJR was 77 cm with a SD of 5.5 cm. Therefore, if a 7% increase is projected the ES can be calculated as follows:

$$ES = \frac{m_B - m_A}{s}$$
$$ES = \frac{1.07 \times 77 - 77}{5.5}$$
$$ES = 0.98$$

In this experiment the researcher wanted to be 60% (power = 0.6, Beta = 1 - 0.6 = 0.4) confident that such a difference in the SJR and AJR pre to post training intervention would be

detected (ie. The null hypothesis would be rejected). Although Cohen (1988) suggests a desirable power of 0.80 (page 56), a power of 0.60 was considered reasonable given the difficulty in obtaining athletes at this competitive level for use in scientific research.

Therefore with an ES of 1.00 (average of 1.02 for SJR and 0.98 for AJR) at an alpha level of 0.05 (one-tailed test) the sample size required was found to be 8 subjects in each group resulting in a power of 0.60 (Cohen, 1988: Table 2.3.2).

## **Experiment Five**

The principle criteria for differentiating the young and old subject groups in this study was the maximal power output produced in the squat jump. Also, it was an aim to determine if any change with training was in fact significant without making a Type II error and whether the percentage change was significantly different between young and old groups. Based on previous research involving young subjects (Wilson et al. 1993) it was anticipated that the ES of this training programme on maximal power output in these previously untrained subjects would be quite large. Therefore, an ES of 1.2 was assumed.

In this experiment the researcher wanted to be 80% (power = 0.8, Beta = 1 - 0.8 = 0.2) confident that such a difference in the power output pre to post training intervention would be detected (i.e. The null hypothesis would be rejected).

Therefore with an ES of 1.2 at an alpha level of 0.05 (one-tailed test) the sample size required was found to be 9 subjects in each group resulting in a power of 0.80 (Cohen, 1988: Table 2.3.2).