UNIVERSITY OF CALGARY

# Ballistic Training: The Effectiveness of Maximal Power Training on Physical Performance

by

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A THESIS

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## Abstract

The main purpose of this study was to compare the effectiveness of ballistic (maximum power) (MxP) and maximum strength (MxS) training on physical performance. Training was periodized into two phases progressing from strength into power development over 10 weeks. Both groups performed plyometrics during the second phase of training. Participants were tested at pre, mid and post training. The MxS and MxP groups improved ($p < 0.05$) their stairclimbing power and squat strength over the course of the study. MxP training also resulted in a within group improvement ($p < 0.05$) in the static jump and peak cycle power from pre to post training. Despite the significant changes within the MxP group, no group effect was detected between both training groups from pre to post testing. The results suggest that MxP and MxS training methods combined with plyometrics are both effective at enhancing lower body power and strength in trained subjects.

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## Dedication

To Mom and Dad

For your all love and support

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## List of Symbols

| | |
|---|---|
| MxS | Maximum Strength |
| MxP | Maximum Power |
| CT | Control |
| CMJ | Counter Movement Jump |
| SJ | Static Jump |
| 1 RM | One Repetition Maximum |
| ANOVA | Analysis of Variance |
| EMG | Electromyography |
| SSC | Stretch Shortening Cycle |
| GTO | Golgi Tendon Organ |
| FT | Fast Twitch muscle fiber |
| ST | Slow Twitch muscle fiber |
| BW | Body Weight |
| Pre | Prior to the training program |
| Mid | Midpoint of the training program |
| Post | After the completion of the training program |
| PPS | Plyometric Power System (modified smith machine for resistance training) |

## Epigraph

The key to improvement in athletic performance is a well-organized system of training. The training program must follow the concept of periodization, be well planned and structured and be sport specific so as to cause the athlete's energy systems to adapt to the particular requirements of the sport.

T.O. Bompa, Periodization of Strength

# CHAPTER ONE

## INTRODUCTION

### Background

The purpose of physical training, as stated by Kabisch (1992), is to cause biological adaptation. Although something can be learned about observing a body in a state of equilibrium, far more can be learned by deliberately disturbing that state and watching it readjust to a new equilibrium (Kabisch, 1992). Human adaptation to stresses, such as physical training, provides an excellent example of how the body responds to a disruption in homeostasis. The degree of adaptation is dependent on three factors, volume, intensity, and frequency of training (Bompa, 1994). The application of these factors determines how much work an individual will perform. However, since the human body does not have an infinite capacity for exercise, determination of how much work an individual can tolerate has to be measured (Kabisch, 1992). In sport, physiologists use fitness tests to determine an individual's strengths and weaknesses such that programs can be designed to improve their weak attributes and either maintain or improve their strengths (Maud, 1994). Once testing information has been gathered, training programs are designed to improve their overall physical capacity to do work which hopefully translates into improved sport performance (Kabisch, 1992).

Physical conditioning relies on the theory that biological systems respond to external stimuli. If the stimuli are repeated frequently, the organism will adapt to them (Kabisch, 1992). Research conducted on how individuals respond to various forms of exercise makes up the foundation for the theory and methodology of training (Kabisch, 1992; Bompa, 1994). Physical conditioning programs are designed to momentarily disrupt the body's homestatic state. Once the demand or stimulus has stopped, the body will respond by returning itself to a new state of equilibrium (Morton, 1997; and Bompa, 1994). The ability to compensate and maintain normal functional values improves if the demands are continually repeated at specific intervals (Kabisch, 1992). Therefore, the body will become more efficient at returning to homeostasis over time.

The physiologist must carefully design the program such that the athlete is able to positively adapt to the imposed stresses. If the stress is not sufficient, no adaptation occurs. If the stress is so great that it cannot be tolerated, injury or overtraining may occur (Bompa, 1994; and Stone, O'Bryant & Garhammer, 1981). In order to reduce injury and overtraining, training programs are often designed using periodized models. Periodized training refers to planning the exercise stimuli into phases or periods (Bompa, 1994). In a periodized program, the overall training plan is broken down into several periods or phases that focus on building specific physiological components. These components are the building blocks of the training program. The exercise physiologist must properly sequence these phases in order to optimize performance at the proper times during the training plan. Organizing training into phases enables the physiologist to determine when they will disrupt the athletes' equilibrium and when they will allow them to compensate for the disruption. The key to planning effective training is to allow for sufficient recovery from the disrupted state such that the body can re-organize itself to the new overcompensated or supercompensated state (Bompa, 1994). Therefore, in the attempt to improve performance for an individual, the physiologist must methodically plan the training program that allows for positive adaptation to the training stimuli.

Training for power in sport has been referred to as the combination of applying strength and speed together (Delecluse, 1997; Fleck & Kraemer, 1997; and Bompa, 1996). Explosive power is one of the main determinants of performance in activities requiring movement sequences at a high velocity or impact. These movements include muscle actions such as throwing, jumping, sprinting and striking. Moreover, explosive power is needed in sports where rapid and accelerating movements occur such as in football, soccer, baseball, hockey, and gymnastics (Newton & Kraemer, 1994).

Various forms of training to enhance power exist since training for speed and strength are typically viewed as two separate entities each requiring a unique form of training (Fleck & Kraemer, 1997). The degree to which strength and speed are developed depends on the requirement of the sport or activity as some sports require more strength than speed. Typically, the goal of each individual is to attain their highest level of power that will benefit them the most in their sport. Numerous studies have tested the effects of plyometric, weight training and weight training-plyometric combined programs on various performance measures. Within these studies, improvements in performance were documented in testing modalities that were specific to the training program. However, differences between studies in program variables such as volume, intensity and training background of the participants have limited the identification of superior forms of training. Despite discrepancies in research design of past training programs, study designs continually improve as new training concepts evolve. Therefore, the search for the most effective methods of developing power for physical performance continues in an effort to maximize biological adaptation.

**Statement of the Problem**

The use of ballistic or maximum power training has become a popular new method for strength coaches and researchers to develop upper and lower body power. The term ballistic infers accelerative, of high velocity and with actual projection into free space (Newton & Kraemer, 1994). ("Ballistic" and "maximum power" are typically referred to as the same training method and are used interchangeably throughout this manuscript.) Typical resistance training exercises that are ballistic include jump squats and bench press throws. Ballistic training at approximately one third of maximum strength has been shown to be as equally effective at increasing strength in comparison to traditional methods such as maximum (heavy) strength training (Wilson, Newton, Murphy & Humphries, 1993; and Lyttle, Wilson & Ostrowski, 1996). However, research has yet to compare maximum strength training to ballistic training, as they would be used in a practical training cycle.

Research has demonstrated that as a single training stimulus, maximum power training is more effective than maximum strength and plyometric training on anaerobic type performance measures such as cycling, jumping and sprinting (Wilson et al., 1993). Generally, maximum strength training is typically combined with plyometric training as a training method to develop power. The combination of maximum strength and plyometric training in comparison to maximum power training alone has reduced the difference in performance between the training methods (Lyttle et al., 1996). Therefore, the next logical step in program design was to combine maximum power with plyometric training to determine if performance can be further enhanced compared to maximum strength and plyometric training. Furthermore, since it is recommended that training programs designed at enhancing power progress from a strength phase to a high velocity (plyometric) phase, this study would be designed with two distinct periodized training cycles (Bompa, 1994). The first phase of the training plan would focus on the development of strength through either maximum power or maximum strength methods. The second phase of training would incorporate high velocity movements into each training group through the use of plyometrics. Therefore, both experimental groups would progress from a predominantly strength related stimulus to high velocity (plyometric) stimulus. This variation in the periodized training program was intended to provide further insight to the effectiveness of ballistic training in comparison to more traditional training methods.

## Primary Purpose

The primary purpose of this study was to determine the effects of two training programs on physical performance. The programs being studied were a periodized maximum strength and plyometric training program (MxS) in comparison to a ballistic (maximum power) and plyometric training program (MxP) over a ten week duration.

## Secondary Purpose

The secondary purpose was to investigate the effects maximum strength training (MxS) and maximum power training (MxP) have on the development of lower body strength over the ten week training period.

## Statement of Hypotheses

1. The MxP (ballistic training) group will show a greater overall improvement in the performance tests when compared to the MxS group throughout the study.

   $H_a$: MxP > MxS

2. It is expected that both training regimes, MxS and MxP, will increase strength to a similar extent, as measured through the 1 RM squat.

   $H_o$: MxP = MxS

## Significance of Study

The search for an effective method for developing lower body power is necessary since no one training regime can presently be identified as the best method. Although identification of a superior form of training is highly dependent on the power requirement of the sport or activity, experimentation with new or modified forms of training to develop power may gradually identify which forms of training are most beneficial. This study was an example of the continuation of modifying and improving upon past training methods such as those conducted by Wilson et al. (1993) and Lyttle et al. (1996). The development of a new form of training may then assist in identifying new variations in effective program design for developing power in individuals.

# CHAPTER TWO

## REVIEW OF LITERATURE

## Muscle Morphology and Resistance Training

### Muscle Fiber Adaptations

Muscle tissue is commonly used to analyze physiological adaptations that occur with resistance training. Changes can often be observed visually through muscular hypertrophy as well as through quantifiable scientific methods. Skeletal muscle is a heterogeneous mixture of several types of muscle fibers (Fleck & Kraemer, 1997). Classification of muscle fiber is dependent on the analysis technique used. Muscle fiber can be classified simply by visual color inspection (red and white), which differentiates fiber type by the fiber color. The more myoglobin the fiber has, the redder it is and hence the greater its oxidative potential (Pette & Staron, 1990). Determination of the speed and shape of the muscle electromyography (EMG) signal also classify fiber types into fast twitch or slow twitch muscle fibers. Fast twitch fibers have a higher rate of force development and fatigue than slow twitch muscle fibers (Pette & Staron, 1990). Complex methods such as metabolic staining of enzymes within the muscle fiber further classifies the fiber type by determining their glycolytic and metabolic characteristics. Fast twitch muscle fibers can be classified as fast glycolytic or fast oxidative – glycolytic, whereas slow twitch muscle fibers are classified as slow oxidative. Moreover, the stability of the myosin ATPase enzyme within each fiber type can be determined which classifies the muscle fibers into Type I (slow twitch) and Type II (fast twitch). This histochemical staining method classifies Type I and Type II muscle fibers by using different pH conditions since different muscle fibers stain at different intensities (acidic to basic) (Fleck & Kraemer, 1997). The result of the specific pH stainings are a continuum of muscle fiber categories reported as Type I, IC, IIC, IIAC, IIA, IIAB, IIB (Staron, Hikida, Murray, Nelson, Johnson & Hagerman, 1992; and Brooke & Kaiser, 1970). In addition, muscles in the human body can be also expressed in terms of their myosin heavy chain (MHC) isoforms. Three MHC isoforms exist referred to as slow (MHCI) and fast (MHCIIa and MHCIIb). These MHC isoforms correspond to the three major types of human skeletal muscle fiber Types I, IIA and IIB. Overall, this detailed and complex classification system allows researchers to identify the exact muscle fiber adaptations that occur as a result of training programs.

In regards to muscle fiber adaptations to resistance training, researchers have discovered that with high intensity resistance training, muscle fiber type transformations occur within a particular muscle fiber sub-type (Staron, Karapondo, Kraemer, Fry, Gordon, Falkel, Hagerman & Hikida, 1994; and Kraemer, Patton, Gordon, Harman, Deschenes, Reynolds, Newton, Triplett & Dziados, 1995). This fiber adaptation is the transformation of Type IIB into Type IIA which has been found to be a common response to resistance training (Fleck & Kraemer, 1997; Staron et al., 1994; Kraemer et al., 1995). Staron et al. (1994) discovered that after eight weeks (16 workouts) of resistance training, the Type IIB muscle fiber types in both men and women decreased from 21% to 7% as confirmed by histochemical assays. The shift of Type IIB fibers to Type IIA suggest that with high intensity resistance training, Type II muscle fibers become more oxidative. Type IIA muscles have the ability to do work under glycolytic and oxidative conditions in comparison to Type IIB fibers which function under glycolytic conditions only (Fleck & Kraemer, 1997). These fiber subtype transformations also begin to take place within a short time period (5 workouts) (Staron et al., 1994).

Muscle fibers are also able to increase in size (i.e. hypertrophy) through resistance training. Hypertrophy is attributed to the increase in size and number of the actin and myosin filaments within the existing muscle fiber (Goldspink, 1992). These changes can also be detected using similar staining assays previously discussed regarding muscle fiber transformations. Although both types of muscle fibers can undergo hypertrophy, Type II muscle fibers make larger relative gains in size when compared to Type I muscle fibers with heavy resistance training (Kraemer et al., 1995). Significant changes in size also typically take longer (6-8 weeks @ 2 workouts / week) to occur in comparison to muscle fiber transformations of Type IIB to Type IIA (Staron et al., 1994). Therefore, improvements in strength or power that occur within 6-8 weeks of resistance training are primarily due to muscle fiber transformations, a gradual increase in the size of the myofibrils and neural adaptations (Staron et al., 1994).

**Neural Adaptations**

Resistance training methods are based on the size principle for motor unit recruitment (Fleck & Kraemer, 1997). According to this principle, the smaller or low threshold motor units are recruited first which are predominantly Type I muscle fibers. As the load placed upon the muscle increases, higher threshold motor units, which are predominantly Type II muscle fibers, are recruited. In resistance training, heavy loads such as 3-5 repetition maximum (RM), require the recruitment of Type II fibers in order to generate sufficient force to control and lift the imposed load (Fleck & Kraemer, 1997). However, according to the size principle, high threshold motor units are still only recruited after lower threshold motor units have been activated and can no longer produce sufficient force to counteract the load. A few exceptions to the size principle are believed to exist.

Kraemer, Fleck and Evans (1996) suggest that it may be possible to inhibit lower threshold motor units and instead activate higher threshold motor units. The purpose of this change in motor unit recruitment patterns would be to enhance the rate of force development and power production of the musculature. High resistance or maximum strength training may be one method that enhances high threshold motor units involvement since it requires very high levels of Type II muscle fiber recruitment to overcome the intense loads (Delecluse, VanCoppenolle, Willems & Leemputte, 1995). Delecluse (1997) states that training at near maximal loads is a form of neuronal activation training since loads are typically 90-100% of 1 RM or in the case of eccentric actions supramaximal (> 100%). The near maximum loading will cause fast twitch muscle fibers to be recruited with a high rate of firing in order to overcome the resistance (Delecluse, 1997). This form of resistance training is primarily an advanced method of developing neural factors, which contributes to the increases in strength (Atha, 1981; Bompa, 1993; and Kraemer, Fleck & Evans, 1996). These neurological changes occur during the early phases (2-8 weeks) of training whereupon further increases in strength are attributed primarily to muscle hypertrophy (Kraemer et al., 1996; and Staron et al., 1994). Therefore, training at near maximal loads appears to produce a positive adaptation of Type II fibers, where these fibers are recruited more readily.

The specific neural changes that occur as a result of high resistance training include increased neural drive to the muscle, increased synchronization of the contractile apparatus and a decreased inhibition of protective mechanisms, particularly the golgi tendon organs (Fleck & Kraemer, 1997, and Kraemer et al., 1996). The majority of studies have demonstrated that in the early phases of a high resistance training programs, increases in voluntary activation of the muscle is the largest contributor to strength gains (Sale, 1992; Häkkinen, 1989; and Moritani, 1992). Increases in neural drive to the muscle refer to the number and amplitude of nervous impulses and are typically measured by EMG techniques (Fleck & Kraemer, 1997; and Sale, 1987). EMG techniques measure the electrical activity within the muscle and nerves that indicate the amount of neural drive (Fleck & Kraemer, 1997). Moritani and DeVries (1979) demonstrated that the major contributor to increases in strength during the first 3-4 weeks of training was an increase in neural activation as measured by IEMG (surface EMG). Subsequent increases in strength were due to muscular hypertrophy since muscle fiber size increased while EMG activity remain the same (Sale, 1992). Possible explanations for the changes in the neural drive include an increased net excitation of the prime mover motor neurons from either an increased excitatory input, reduced inhibitory input or both (Sale, 1992). Other neural factors that may explain the increases in strength include more efficient synchronization of muscle fibers and possible recruitment of additional motor units (Sale, MacDougall & Upton, 1983; and Moritani & DeVries, 1979).

Enhancement of force production has also been attributed to inhibition of protective mechanisms such as the golgi tendon organs which protect the muscle from extreme tension development (Guyton & Hall, 1996). This protective reflex can be reduced in order to enhance force production under conditions of hypnosis (Ikai & Steinhaus, 1961). However, since hypnosis is typically not used in the training environment, inhibition of protective mechanisms can also be reduced if a pre-activation of the antagonist muscles occurs prior to a maximal lift. Caiozzo, Perrine & Edgerton, (1981) demonstrated that during the bench press movement, force production was enhanced if the bicep and scapula adductors were immediately activated prior to performing the lift thereby inhibiting the protective mechanisms.

Improvements in strength from resistance training programs are also dependent on the individual. Häkkinen (1989) states that the training status of an individual involved in the high resistance training will affect the degree of neuro-muscular adaptation. Untrained subjects will show greater increases in neural adaptation during the initial weeks of adaptation compared to highly trained subjects (Häkkinen, 1989). This difference in adaptation implies that the relative training load should be greater in trained athletes than in untrained. Highly trained athletes who trained with loads of 70-80% of 1 RM actually had their IEMG decrease when compared to training with 80-90% of 1 RM which produced increases in IEMG activity (Häkkinen & Komi, 1985). Therefore, to develop maximum strength in trained individuals, loads should be at least 80% of 1 RM to produce a positive neural adaptation (Häkkinen & Komi, 1985; and Bompa, 1993).

**Hormonal Adaptations**

Hormones have been evaluated in conjunction with strength training research because changes in the hormonal profile have been known to take place in relation to the intensity and duration of training programs (Häkkinen, 1989). The role of hormones in the adaptation process to resistance training is complex and highly integrated with many factors. Endocrine function is dependent on factors such as training background, nutritional status, caloric intake, stress, sleep and disease (Kraemer et al., 1996). Häkkinen (1989) has stated that is it difficult to accurately compare studies measuring hormones due to the variance in intensity and duration of the training stimuli. Short term studies have reported only minor changes in the androgren profile of hormones such as testosterone, luteinizing hormone and growth hormone (Häkkinen, 1989). The hormonal change to a short intensive training stimulus usually returns to baseline with a few days of rest (Häkkinen & Pakarinen, 1991). However, during a prolonged resistance training study of two years with elite athletes, increases in testosterone, luteinizing hormone and follicle stimulating hormone were evident. This suggests that prolonged strength training may influence the pituitary and possible hypothalmic function (Häkkinen, Pakarinen, Alen, Kauhanen & Komi, 1988).

Häkkinen, Pakarinen and Alen (1987) discovered an increase in the testosterone / cortisol ratio, a measure of anabolic /catabolic status, over six months of training with elite weight lifters. However, the increase only became evident during the last four weeks of training. These changes concomitantly took place with an increase in strength. Therefore, it appears that the hormonal response is sensitive to the overall volume and intensity of training. Häkkinen et al. (1987) also discovered that during stressful periods, a decrease in testosterone / cortisol ratio was apparent. Once the volume of training was reduced to normal levels, the anabolic / catabolic ratio re-attained its baseline values. This return to normalcy was also accompanied by a slight increase in weight lifting performance.

For practical application, the monitoring of hormonal levels and strength can be useful in evaluating the trainability and health status of an individual (Häkkinen, 1989). Training volume and intensity can be adjusted according to the hormonal profile in an attempt to enhance performance while avoiding overtraining. Overall, the complexity of the endocrine system has just started to be understood. As monitoring techniques improve, so will the understanding of the hormonal environment in response to training stimuli (Kraemer, et al., 1996).

## Nervous Control and Behavior of Plyometric Movements

### Stretch Shortening Cycle

Training the stretch reflex or stretch shortening cycle (SSC) has been utilized in sport to enable individuals to more forcefully contract their muscles (Aura & Komi, 1986, Guyton & Hall, 1996, Bompa, 1996, and Komi & Bosco, 1978). This area of applied training has been extensively researched and used in the field setting as an effective form of power training (Bauer, Thayer & Baras, 1990; Häkkinen, Komi & Alen, 1985; Bompa, 1993; Komi & Bosco, 1978; Wagner & Kocak, 1997; Blattner & Noble, 1979; Häkkinen & Komi, 1985; Bosco, Tihanyi, Komi, Fekete & Apor, 1982; Lyttle et al., 1996; and Wilson, Newton & Murphy, 1993). The physiology of the stretch reflex is a complex and highly integrated form of motor control between the central nervous system (CNS), agonist and antagonist muscles. The relationship between the CNS and the muscle being stretched begins with a sensory stretch receptor called the muscle spindle.

The muscle spindle is a sensory mechanoreceptor composed of several (3-12) intrafusal fibers that are sensitive to both the magnitude and rate of change in length of the muscle (Guyton & Hall, 1996; and Bompa, 1996). These intrafusal fibers are connected to the much larger surrounding extrafusal fibers in a glycocalyx of connective tissue (Guyton & Hall, 1996). Unlike extrafusal fibers, the central region of intrafusal fibers lacks the ability to contract since they do not contain the contractile proteins, actin and myosin. The non-contractile portion of the skeletal muscle fiber is also referred to as the nuclear bag and nuclear chain fibers since both types contain cell nuclei. Nuclear bag intrafusal fibers contain a large number of nuclei in a congregated 'expanded bag' compared to nuclear chain fibers which have fewer nuclei, half the overall length and are arranged in a chain-like structure (Guyton & Hall, 1996). The main difference between nuclear bag and nuclear chain intrafusal fibers are that nuclear bag fibers contain primary and secondary afferent neurons while nuclear chain fibers contain only secondary sensory neurons. Primary or type Ia and secondary or type II sensory endings are also referred to as annulospiral endings which are coil-like in appearance (Guyton & Hall, 1996; and Bompa, 1996). In a stretch reflex, the muscle spindle detects a change in muscle length and produces a sensory response of type Ia neurons in dynamic and static situations. Type II sensory responses occur in static situations only. Dynamic situations usually involve very rapid changes in muscle length and are regulated by type Ia afferent neurons. The high conduction velocity of type Ia neurons assists in the immediate compensation response to stimulate a muscle contraction.

A monosynaptic (afferent - anterior motor neuron - efferent) response occurs in stretch reflex situations where the sensory neuron enters the dorsal root of the spinal cord and then synapses directly with an efferent motor neuron at the anterior horn of the spinal cord. Monosynaptic responses generally occur with primary Ia afferent endings while type II afferent endings terminate on multi-interneurons in the gray matter of the spinal cord thereby producing a more delayed response (Guyton & Hall, 1996). Once the afferent neuron has synapsed with an interneuron(s) in the spinal cord, an efferent response occurs in the form of gamma and alpha motor neurons. The gamma motor neurons control the intrafusal fibers while the alpha motor neurons control the extrafusal fibers. With regards to the muscle spindle, gamma motor neurons control the shape of the intrafusal fiber (nuclear bag and nuclear chain) by innervating the ends of the intrafusal fibers, which are capable of shortening (Fleck & Kraemer, 1997). This co-activation of alpha and gamma motor neurons enables the intrafusal fibers to contract in unison with the extrafusal fibers (Guyton & Hall, 1996).

Two types of gamma motor neurons exist and are associated with the type of response produced by the muscle, static or dynamic, similar to type Ia and II afferent responses. Static responses are controlled by gamma-s motor neurons and are directed at nuclear chain intrafusal fibers whereas dynamic responses are controlled by dynamic-d gamma motor neurons and are directed a nuclear bag intrafusal fibers (Guyton & Hall, 1996). The role of two different gamma motor neurons are to monitor changes in muscle length and duration of contraction. During a stretch reflex (monosynaptic), immediately gamma-d neurons are excited until the muscle has reached its new length that occurs within a fraction of a second. Once the muscle has been stretched to its new length, gamma-s motor neurons then replace the gamma-d neurons and are excited as long as the muscle remains at its new length. The dynamic response to a rapid stretch of the muscle, detected by the primary receptors, are extensively used in plyometric training. Plyometrics utilize the dynamic afferent response since the exercises cause an rapid stretch of the muscle resulting in an immediate alpha motor neuron stimulus to the muscle for contraction (Bompa, 1996). The static response is to continue to control the shape of the intrafusal fibers as long as the muscle is being stretched (Guyton & Hall, 1996).

The role of alpha motor neurons, as noted above in the plyometrics example, is to stimulate the extrafusal fibers for muscle contraction. In addition to the alpha motor neuron response, a gamma motor neuron stimulus is sent from anterior horn of the spinal cord to excite the intrafusal fibers. Alpha and gamma motor neurons therefore work in conjunction with one another such that the intrafusal and extrafusal fibers contract and lengthen in unison. This is also referred to as the alpha-gamma co-activation as previously mentioned (Fox, Bower & Foss, 1993; Guyton & Hall, 1996). The purpose of contracting the intrafusal and extrafusal fibers is two fold. First, it keeps the central portion of muscle spindle from changing length and thereby preventing opposing fiber contraction. Secondly, the co-activation acts as a dampening function to smooth out or coordinate muscle contractions (Guyton & Hall, 1996). Execution of smooth, voluntary movements by the gamma efferent system are directly controlled by the bulboreticular facilitary region of the brain stem which receives impulses from the cerebellum, basal ganglia and cerebral cortex (Fox, Bower & Foss, 1993; and Guyton & Hall, 1996).

The SSC can be described in normal muscular movements such as in running and walking since eccentric (muscle lengthening) and concentric (muscle shortening) contractions occur periodically. Komi (1986), states the final action of the SSC (concentric contraction) occurs with greater force or power output than a movement initiated by concentric contraction alone. Therefore, muscle lengthening prior to a concentric contraction increases the force output. The increase in force output due to an eccentric pre-stretch has been attributed to two main reasons; the stretch reflex potentiation due to enhanced myoelectrical and elastic energy stored within the muscle and tendon (Komi, 1986; and Koutedakis, 1989). The potentiation of muscular contractions following a pre-stretch is related to the length of time between the stretch and shortening phases (Komi, 1986). This time between phases is referred to as the amortization phase or 'shock absorbing phase' (Bompa, 1996). Komi (1986) and Bompa (1996) both state that the longer the amortization phase, the greater the loss of potential energy or power. Shorter amortization phases lead to more powerful contractions (Bosco & Komi, 1980). From a training perspective, exercises that cause athletes to increase their amortization phase because of an inability to counter the downward force of an eccentric contraction, lose the effect of the SSC and hence do not demonstrate the potentiated muscular contraction (Komi, 1986; and Bompa, 1996). Overall, the main purpose of prestretching the muscle in basic movements, such as the counter movement jump, is to enhance the force-velocity curve by shifting it to the right. Therefore, for a given velocity in a force-velocity relationship, prestretching increases force output (Komi, 1986).

Utilizing the elastic energy stored within the muscle and tendon also enhances force production in SSC movements. Elastic energy is generated from the prestretch phase or eccentric work. Eccentric work has been found to be more efficient than concentric work at a ratio of 1.20 to 1.00 (Davies & Barnes, 1972). Kaneko, Komi &

Aura (1984) have reported that the mechanical efficiency of eccentric work can be as high as 150%. Bosco (1986) states that the mechanical efficiency of eccentric exercise can be further potentiated by increasing the stretching velocity. Therefore, the greater the pre-stretch rate, the more potential mechanical energy stored within the muscle to be utilized during the subsequent concentric contraction. This elastic energy is taken up in the elastic elements arranged in series within the sacromeres of the myofiber as well as within the tendon (Bosco, Tihanyi & Komi, 1982; Komi, 1986; and Koutedakis, 1989). It is suggested that the pre-stretch causes the myosin heads to rotate backwards to a position of higher potential energy. This implies that the elastic energy is stored in the cross-bridges and can be transferred into positive work if the muscle is allowed to shorten immediately after the stretch (Bosco et al., 1982). In regards to tendon elasticity, the tendon also has recoil properties that once stretched eccentrically will supply energy to the muscle contraction.

Elastic energy potential is also dependent on the muscle fiber type of the individual. Bosco et al. (1982) discovered that individuals who are fast twitch (FT) muscle fiber dominant can store a greater amount of mechanical energy if the pre-stretch movements are performed with high speed and low angular displacements. However, individuals who are slow twitch (ST) muscle fiber dominant store more energy with slower stretches and larger angular displacements. Furthermore, Bosco, Tihanyi & Latteri (1986) demonstrated in a fatigue state that FT muscle fibers are more capable of re-using stored amounts of elastic energy than ST fibers. This was attributed to the decrease in the cross-bridge attachment-detachment cycle in FT fibers thereby allowing a greater number of cross-bridges to remain attached. This prolonged attachment of the cross-bridges maintained the ability to re-use elastic energy in comparison to ST fibers (Bosco et al., 1986). These results indicate that the sacromere lifetime of FT fibers is longer when compared to ST fibers in a fatigued state.

Bosco, Tarkka and Komi, (1982) suggest that elastic energy accounts for more than 2/3 of the total potentiation of SSC movements. Within this elastic energy, approximately 35% of the energy is derived primarily from tendons (Anderson & Pandy, 1993). Although the magnitude of potentiation is determined by the magnitude of the prestretch, excessive eccentric force will also cause an inhibitory response rather than an excitatory response which are both controlled by the golgi tendon organs (Komi, 1986).

**Golgi Tendon Organs**

In a stretch reflex, another sensory receptor, the golgi tendon organ (GTO), also plays and important role in controlling muscle contraction. Golgi tendon organs are sensory receptors encapsulated in muscle tendon fibers situated in musculotendinous joints that are sensitive to changes in muscle tension rather than muscle length (Fox et al., 1993). The role of the GTO is opposite to that of the muscle spindle. The golgi tendon organ causes an inhibitory response in the spinal cord preventing the anterior motor neurons from firing, thereby causing muscle relaxation. This response occurs under intense and very rapid increases in muscle tension (Guyton & Hall, 1996). Feedback to the spinal cord is provided by type Ib afferent neurons which provide sensory information at a rate very similar to type Ia afferent neurons. Both dynamic and static responses produced by the GTO are similar to muscle spindles. Sudden increases in tension cause dynamic responses, however, this response terminates within a fraction of a second leading to the static response which provides the nervous system with instantaneous information pertaining to muscle tension (Guyton & Hall, 1996). This constant monitoring of muscle tension is controlled through higher brain centers, particularly the cerebral cortex and cerebellum (Guyton & Hall, 1996). Under extreme conditions of muscle tension, the GTO can elicit an inhibitory effect called the lengthening reaction causing total muscle relaxation. The purpose of this response is thought to be a protective mechanism against severe muscle damage such as tendon - bone avulsions and muscle tearing. Therefore, GTOs and muscle spindles work together to protect the muscle from injury as well provide information to execute smooth coordinated movements (Fox et al., 1993).

The GTO tension monitoring system also has the potential to adapt to a training stimulus. In training, muscles can generate high forces which may cause the inhibitory mechanism to respond (Caiozzo, Perrine & Edgerton, 1981). However, repeated exposure to high loads may reduce this tension-limiting mechanism (Caiozzo et al., 1981). Maximum strength training with heavy loads is one method of training this neural mechanism (Caiozzo et al., 1981; and Bompa, 1994). This reduction of the golgi tendon reflex resulting in enhanced force production can also occur with explosive type power training. Häkkinen and Komi (1985) used several jumping type exercises with and without light loads and discovered an increased EMG response indicating enhanced neural activation of the leg extensor muscles. These increases in muscle activation also correlated with improvements in counter movement and squat jump height. The increase in force production and vertical jump height was thought to be attributed to improved firing frequencies, motor unit recruitment and changes in the inhibitory reflexes

(Häkkinen & Komi, 1985). The reduction of the tension-inhibition reflex further demonstrates the importance of neural adaptations to resistance and explosive type training.

## Methods of Training for Power Development

The following topics will include discussions of the effects of specific training methods on physical performance with particular reference to the lower body extremities.

### High Resistance Training

Delecluse, Van Coppenolle and Willems (1995) compared the effects of high resistance and high velocity training on sprint performance. The experiment progressed over 9 weeks with increasing intensities from 10 RM down to 3-5 RM in the final two weeks. This high resistance training was effective at improving the acceleration phase of a sprint (0-10 m), however it did not have an effect on maximum speed, speed endurance, and total sprint time. Moss, Rèfsnes, Abildgaard, Nicolaysen and Jenson (1997) also discovered that maximum strength training (90% 1 RM) was found not only to be effective at increasing strength, but also power over a wide range of loads (15-90% of 1 RM). These findings suggested that maximum strength is important for performance at light loads. Wilson, Murphy and Goirgi (1996) found similar results with resistance training (6-10 RM) by demonstrating significant improvements in high acceleration tasks such as in the counter movement jump (CMJ) and concentric jump squat. Hoff and Almasbakk (1995) used maximum strength training at 85% of 1 RM with female handball players. Significant increases in bench press strength, standing shot throw and a 3-step running shot throw were discovered. This training study not only verifies the role of maximum strength training for increasing force output, but also in the rate of force development since high velocity throwing motions require a certain level of strength to be successful. Moreover, this study supports Delecluse et al. (1995) since high resistance training also improved the 0-10 m start time providing further evidence for the role of maximum strength training in the initial rate of force development. In addition, Schmidtbleicher and Haralambie (1981) demonstrated that training with very high loads (90-100% of maximum voluntary strength) produced significant gains in strength (MVC), increases in neuromuscular excitability and decreases in the shortening of contraction time. It was also postulated that training at high loads predominantly involves the recruitment of fast twitch fibers, which are necessary for explosive movements.

Wilson et al. (1993) tested the effects of resistance training (75-85% 1 RM) on dynamic athletic performance. Significant improvements in a maximal 6 s cycle ergometer test, static jump (SJ) and CMJ over 10 weeks of training were discovered. The effects of resistance training (80% 1 RM) have also proven to be beneficial to specific field tests such as 2500 m rowing and distance rowed in 90 s (Kramer, Morrow & Leger, 1993). The development of maximum strength is therefore seen as a contributing factor in muscular power. All explosive movements must start from zero or slow velocities and it is within these initial phases that strength can contribute to power development (Bompa, 1993; and Newton & Kraemer, 1994). Maximum strength training consequently works on the high force/low velocity portion of the force-velocity curve (Faulkner, Clafin & McCully, 1986). However, as the velocities of contraction increase, slow velocity strength has less impact on the ability to produce high force at rapid shortening velocities, thus limiting its contribution to the development of maximum power (Kaneko, Fuchimoto & Toji, 1983; and Newton & Kraemer, 1994).

**Plyometric Training**

Plyometric exercises emphasize loading of the muscles during an eccentric muscle action in order to produce a more forceful subsequent contraction. The purpose of SSC training is to cause the muscles and nervous system to adapt such that more force is produced in less time (Kramer et al., 1993; DeSpain, 1987; and Lundin, 1985). Bosco, Komi, and Pulli (1982) observed height differences between SJ and CMJ of 18-20% in competitive volleyball players as a result of plyometric training. Häkkinen and Komi (1985) stated that the dynamic stretching and subsequent contracting of muscles involved with plyometric exercises allows for greater improvements in the maximal rate of force development, and thus power, in comparison with traditional weight lifting methods. This improvement can be attributed to the explosive type nature of stretch-shortening cycle (SSC) movements. Typically, explosive movements are 300 ms whereas peak force output usually occurs at 400 ms, therefore, maximum force application to a movement cannot be attained over such a short time (Newton & Kraemer, 1994; and Fleck & Kraemer, 1997). This implies that the slow-velocity strength has a limited role in the rate of force development and further improvements in this rate must be elicited from higher velocity training techniques such as plyometrics.

The most common form of plyometrics used in training studies involves the use of drop jump or depth jump exercises with the vertical jump height being the performance measure. However, due to the vast range of drop heights, repetitions, sets, training days per week, experience of participants, age of participants, drop jump technique and the use of additional weights such as hyper-gravity vests in training studies, it is difficult to determine which method of drop jumping exercises are most effective (Bobbert, 1990). In a review of plyometric training studies up to 1989, Bobbert (1990) suggested that the most effective plyometric program for improving vertical jump was conducted by Bartholomew (1985). Bartholomew (1985) progressively trained physical education college students over a period of 8 weeks, twice per week, with depth jump heights of 50 - 80 cm and repetitions gradually increasing from 23-62. The average gain in vertical jump height was 10.2 cm. This significant increase in jump height was greater than any other study reviewed that focused on enhancing vertical jump performance.

Despite the amount of research conducted with plyometric training, the effectiveness of plyometric training alone in comparison to other forms of training such as weight training is unclear. Some studies have found no significant improvement with plyometric training (Blakey & Southard, 1990; and Poole & Maneval, 1987) while others discovered plyometric training to be no more effective or less effective than conventional methods such as weight training (Blakey & Southard 1990; Ford, Puckett & Drummond, 1983, and Wilson et al., 1993). Holcomb, Lander, Rutland & Wilson (1996) attempted to correct problems with determining the effectiveness of plyometric training by comparing conventional depth jumps, weight training (4-8 RM), modified depth jumps and CMJ training. Exercise volume was equated for each group. No significant differences were found between the various training groups, but each group did significantly improve their vertical jump and power. However, the lack of significant differences between training groups may be attributed to the lack of sensitivity of using a vertical jump test to detect changes as a result of training.

Wagner and Kocak (1997) compared athletic vs. non-athletic students in a progressive plyometric program and discovered both groups significantly improved their vertical jump, 50 m dash and the Margaria-Kalamen stairclimbing test. Although significant improvements were noted in the performance tests due to plyometric training, the average change in VJ and the 50 m sprint was less than 1% whereas the power increase for the stairclimbing test ranged from 17.7-19.4%.

Overall, Schmidtbleicher and Gollhofer (1982) suggest that the best solution to determining the appropriate height for drop jumps is to adjust the distance dropped such that the athletes are still able to prevent their heels from hitting the ground upon landing. This training technique is used to reduce the amortization phase of the SSC thereby enhancing concentric force production (Bompa, 1996). Bobbert (1990) suggests that the most effective method of designing plyometric exercises is to first familiarize and introduce the subjects to regular jumping exercises, then to a weight training program, and finally to a drop jump training program. In addition, Bompa (1996) recommends that plyometric exercises should progress from low impact to high impact exercises and for young developmental athletes should take place over period of 2-4 years. The gradual progression of plyometrics is to allow for the proper adaptation of ligaments, tendons, bones and spine to the training stimulus (Bompa, 1996).

**Combined Resistance Training and Plyometrics**

The rationale for integrating slow velocity (high resistance) and high velocity (low resistance) training is based on the power equation (power = force x velocity). If an athlete is to maximize power potential for sport, both components should be trained (Newton & Kraemer, 1994; and Bompa, 1994). The development of each component is dependent on the power requirements of the sport (Fleck & Kraemer, 1997). Typically, high resistance training is performed with free weights and power is developed with the application of plyometrics (Wilson et al, 1993; Lyttle et al., 1996; Bompa, 1994, 1996; Häkkinen & Komi, 1985; Blattner & Noble, 1979; Lundin, 1985; and Fry, Kraemer, & Weseman, 1991). It appears that weight training and plyometrics modify different capacities of the neuromuscular system. This can explain the adoption of both forms of training into one training program in an attempt to maximize changes in performance.

For example, Adams et al. (1992) discovered that after a six-week training period, the combined squat and plyometric group had a significantly greater increase in vertical jump (10.7 cm) compared to the squat only (3.3 cm) and plyometric only (3.8 cm) training groups. Häkkinen and Komi (1985), tested the effects of explosive type training combined with resistance training (60-80% 1 RM) on EMG and force production of the leg extensor muscles. The forms of explosive type training included loaded CMJ jumps with 10-60% of 1 RM, horizontal hurdle hops and drop jumps of 30-60 cm. Significant increases were discovered in SJ (21% increase), CMJ (31% increase), and in the neural activation of the vastus lateralis and vastus medialis. Blakey and Southard (1987) also found improvements using a combined resistance and depth jump program on leg press strength (1 RM) and power (Margaria anaerobic power stairclimb test). Recently, Lyttle et al. (1996) compared the effects of maximal power training (ballistic jump squats @ 30% 1 RM) to combined weight training (6-10 RM) and depth jumps. Both training programs were equally effective at improving SJ, CMJ, running jump (RJ), 6 s anaerobic power cycle, and 1 RM squat strength. This study was also a follow-up from the Wilson et al. (1993) study, which individually tested the effects of plyometrics, heavy weight training, and maximal power training on similar performance measures. Wilson et al. (1993) found that maximal power training was the most effective method for improving performance. However, when plyometrics and weight training were combined as in the Lyttle et al. (1996) study, the difference between groups was not significant as previously stated.

**Maximum Power Training**

Maximal power training as termed by Wilson et al. (1993) and Lyttle et al. (1996) can also be referred to as ballistic training as stated earlier. Typical ballistic training exercises that are examined in research include loaded jump squats, vertical jumps, bench press throws and the seated shot put. Ballistic training has received interest in recent years as a method of power training since ballistic training movements involve training with high velocities and rates of acceleration of the exercising limbs. Wilson et al. (1993) and Berger (1963) are two of many studies that identified a deficiency with traditional weight training exercises to develop explosive power. Elliott, Wilson and Gregory (1989) discovered that when lifting 1 RM loads (100%), 23% of the concentric contraction in a bench press is deceleration. This deceleration phase increases to 52% of the concentric phase of the lift when loads are decreased to 81% of 1 RM. In a training setting, athletes will often use loads similar to 81% of 1 RM in order to train for power. However, as Elliott et al. (1989) discovered, decreasing the load, decreases the acceleration component of the lift and therefore diminishes the stimulus of training for power. The larger deceleration phase with lighter loads results from a decreased activation of the agonists and an increase activation of the antagonists (Newton, Kraemer, Häkkinen, Humphries & Murphy, 1996). Consequently, subjects who are attempting to train for power are in fact training predominantly their antagonistic muscles to decelerate the load rather than training the agonists to accelerate the load. Fleck & Kraemer (1997) recommend that the deceleration can be offset with ballistic training.

Several researchers (Kaneko, Fuchimoto, Toji & Suei, 1983; Wilson et al., 1993; and Lyttle et al., 1996) have shown that trained individuals should train at velocities that maximize power output in order to increase explosive power. This maximal power output is produced at a resistance of 30% of maximum strength (Kaneko et al. 1983; Wilson et al. 1993; Lyttle et al. 1996; Berger, 1963; and Faulkner, Clafin & McCully 1986). In addition, 30% of 1 RM was also found to produce the greatest increase in force and power over the entire concentric velocity range (Kaneko et al. 1983; and Moss et al., 1997). Wilson et al. (1993) compared the effects of 10 weeks of training using traditional back squats (6-10 RM), jump squats at 30% 1 RM, and plyometrics (drop jumps) on VJ, 30 m sprint, 6 s anaerobic power cycle, isokinetic leg extension and a maximal isometric test. Wilson et al. (1993) discovered that the ballistic jump squat group achieved the best overall results in enhancing dynamic athletic performance. In particular, the jump squat group had significantly greater increases (18%) in vertical jump performance compared to plyometric (10%) and the resistance training (5%) groups. These results were similar to Berger (1963) who also found that jump squats performed with resistances that maximize mechanical power output (30% 1 RM) led to greater increases in VJ when compared to traditional weight training, plyometrics or isometric training. However, the degree to which this increase in power output through ballistic training will transfer to athletic performance may depend on whether the mass being moved represents a resistance similar to 30% maximum voluntary contraction (MVC) (Fleck & Kraemer, 1997). From a practical standpoint, this light load is ideal for jump squats or bench press throws since subjects can accelerate the load at a high rate, thereby working the high velocity portion of the F-V curve and the agonist muscles. Furthermore, if the rate of contraction using 30% 1 RM is similar to movements performed in an training setting, this form of training may beneficial to athletic performance by conforming to the principle of specificity of training (Bompa, 1993).

**Conversion Phase: Shift of Strength into Power**

One of the most important training guidelines used in sport is the application of the training stimulus into a sport-specific modality. This application has been referred to as the conversion phase in a training cycle (Bompa, 1993). A classic periodization macrocycle for strength/power sports uses five mesocycles. The first of these cycles is a hypertrophy phase followed by a strength phase, power phase, peaking phase and finally an active rest phase (Stone et al., 1981). Bompa (1993) states that this conversion or transformation phase of strength development into power needs to occur over a period of approximately one to two months for the adaptation to be fully effective. It is also recognized that this length of the conversion phase is variable depending on the type of training employed and the power requirements of the sport (Bompa, 1994).

Typical strength development programs consist of workloads of at least 80-85% of a person's repetition maximum in order to effectively shift the force-time curve effectively to the left (Bompa. 1993). Bompa (1993) suggests that the isotonic maximum load method (MLM) is the best method of maximum strength training pertaining to dynamic sports. This type of dynamic free weight training, due to the heavy loads involved (4-6 RM), causes an increased recruitment of fast twitch muscle fibers as well as improved synchronization of motor units (Häkkinen & Komi, 1985; Häkkinen, Komi & Alen, 1985; and Bompa, 1993). Maximum strength (MxS) training is typically inserted into a periodized training cycle prior to power training (Bompa, 1993). Training is organized in this format such that athletes finish their training plan in an explosive physiological state. Planning a training regime that placed MxS training as the last phase prior to a sporting competition or testing scenario would be inappropriate due the lack of power development. This is because it is important not only to generate sufficient force, but also be able to use such force with speed, which is essential in most power-oriented sports.

Typical power development programs consist of either isotonic or dynamic constant external resistance (DCER) training performed with 30-85% of 1 RM. Common forms of power training include ballistic, power-resisting and plyometric training (Bompa, 1994 & 1996; and Fleck & Kraemer, 1997). Individually, maximal power training has demonstrated to be a significantly superior form of training when compared to the plyometric and resistance training programs as previously mentioned (Wilson et al., 1993). This implies that maximal power training is highly effective at improving dynamic athletic performance in selected tasks. However in the Wilson et al., (1993) study, the resistance-training group did not perform any high velocity exercises to convert the significant gains in strength into an applied power state. Conversely, the plyometric group did not train for maximum strength thereby limiting the degree of power development. It therefore can be postulated that maximal power training was the most effective training strategy since both strength and power methods were combined into one training program to optimize power development (Wilson et al., 1993).

Lyttle et al. (1996) attempted to bridge this lack of conversion between the strength and plyometric training groups. This study (Lyttle et al., 1996) combined the strength and plyometric training methods and then compared it to a maximal power training group as used in the Wilson et al. (1993) study. Both training regimes were found to be equally effective in enhancing a variety of performance measures (40 m sprint, CMJ, SJ, RJ, 6 s cycle, 1 RM squat). Although, no significant differences were found between training groups in the Lyttle et al. (1996) study, limitations within each training group design may have affected the results. These include the lack of a properly periodized combined resistance and plyometric training program. In addition, increases in resistance training volume were coupled with increases in the volume of plyometric exercises throughout the 10 weeks of training. The problem with simultaneously increasing the volume of strength and plyometric exercises together is due to the large difference in the velocity of muscular contractions within these methods (Bompa, 1993; and 1994). This could result in a conflicting training stimulus applied to the body.

Development of maximum strength should also be performed with resistances of at least 85% of 1 RM (4-6 reps) to maximize neural factor development as previously mentioned. Lyttle et al. (1996) used resistances typically less than 80% 1 RM (6-10 reps) to develop maximum strength. In addition, Lyttle et al. (1996) mentioned that the lack of training specificity with the plyometric training might have limited speed development in the 40 m sprint. Incorporation of horizontal as well as vertical plyometric training may have improved the sprint times. Lastly, although maximal power training increases 1 RM strength due the high acceleration component (force = mass x acceleration of the external load + mass x acceleration due to gravity) the inclusion of higher velocity methods of power training, such as plyometrics, may further enhance performance by converting the gains in strength into power.

# CHAPTER THREE

## METHODOLOGY

### Overview of methodology

Prior to commencement of training, all subjects underwent pre-experiment testing of the performance variables. Phase one of the study required the subjects to complete four weeks (weeks 1-4) of training twice per week in either the maximum power and plyometric (MxP) or maximum strength and plyometric (MxS) training groups. At week 5, mid-experiment testing was completed in which the subjects were allotted one week of rest from training. The second phase of the study included four more weeks of training (weeks 6-9). Both groups, in the second phase, performed plyometric training in addition to a reduced of volume of the training they performed in the first phase. At the completion of training (week 10), post-experiment testing was conducted measuring the same variables as in the pre and mid testing sessions. See Appendix A.

### Setting

Fitness and Lifestyle Centre, University of Calgary; and Human Performance Laboratory, Faculty of Kinesiology, University of Calgary, Calgary, Alberta.

### Subjects

Thirty-nine subjects, 19 male and 14 female, participated in the experiment. The sporting background of the subjects included male and female varsity hockey, senior men's rugby, figure skating, volleyball, mountain bike racing, synchronized swimming, snowboard racing, university gymnastics, baseball and modern dance. The participants all had at least one-year of previous weight training experience. Six female soccer players volunteered as the control group. Subjects were not assigned to the control group due to the lack of participation adherence to the study and controlling for additional training. The female soccer players in the control group all agreed to maintain and not engage in any new forms of training other than what they were already participating in. Over the 10 week training period, 4 subjects withdrew for reasons unrelated to training. Two MxS and one MxP subject dropped out of the experiment due to incurring injuries from participating in their respective sport. One MxP subject failed to complete the study due to personal reasons. Overall, 14 MxS, 15 MxP and 6 control subjects completed the study. The subject characteristics are displayed in Table 3 and the subjects' sporting background is reported in Table 4.

## Inclusion / Exclusion Criteria

The criteria set forth for participant involvement in the study consisted of subjects having at least one year training experience and being able to squat at least their own body weight (Fleck & Kraemer, 1997; Bompa, 1996). This was to ensure that the subjects had adequate experience and strength levels required to participate in these advanced training programs. Strength levels were determined during the pre-experiment testing. Two subjects were not allowed to participate in the study because they were unable to successfully squat their own body weight. In addition, participants were required to be free of injuries, which may have affected their ability to participate in their assigned training group. Injury status was determined through the completion of a participant information questionnaire and physical activity readiness questionnaire (PAR-Q) (Appendix F).

## Ethics

The Faculty of Kinesiology Ethic Panel at the University of Calgary approved the experiment protocol (see Appendix E).

## Measurements of Physical Performance

The selection of variables for this study was based primarily on performance based measures. Quantifiable measures such as sprinting time, vertical jump, leg turnover rate, foot speed and strength were the desired outcomes. These measures were chosen to extend the applicability of the results to a practical setting. A sport physiologist or strength coach may then be able to determine if the results of this study could be directly used as a part of their athlete's training plan.

One week prior to initial testing, each subject was familiarized with and completed a full practice testing session. Performance tests were scheduled at three separate intervals over the 10 week training study: 1) prior to training 2) mid point 3) post training (see Appendix A). Verbal encouragement was used for each of the following tests. The best result for each test was used in the statistical analysis.

### Vertical Jump: Static and Counter movement Jumps

The static jump (SJ) and counter movement jumps (CMJ) were performed on a Kitzler Force Platform at a sampling rate of 1000 Hz based upon the procedures of Young, McLean and Ardagna (1995). Subjects performed a 10 min warm-up consisting of running and stretching prior to the testing. Two attempts were permitted where the best jump height was recorded for the SJ and CMJ. Jump height was calculated by measuring the duration of time the subject spent in free space (take-off until landing back on the force plate). The vertical jump data measured by the force plate was sent to a computer for graphical interpretation and subsequent analysis (See Appendix B for the SJ and CMJ force output graphs). See Figure 1 and 2 for photographs of the vertical jumps. The kinematic equation used (Serway. 1990):

Jump height (cm) = $\frac{1}{2}(g * t^2)$

Where:

$g$ = acceleration due to gravity (9.81 $m \cdot s^{-2}$)

$t$ = duration of time in free space (s)

All vertical jumps were performed with the participant's hands on their hips for the entire range of motion as previously tested by Komi and Bosco (1978) and Bosco, Tihanyi, Komi, Fekete and Apor (1983). Static jumps were executed by having each subject squat down to a knee angle of 120° measured manually by a goniometer (Lyttle et al., 1996). Once the subject had reached the desired knee angle in the static position, a verbal signal was given by the test administrator to perform a concentric contraction of the leg extensors. Counter movement jumps involved subjects starting from an upright position on the force plate and then performing a fast eccentric knee bend prior to an explosive concentric contraction for maximal jump height (Lyttle et al. 1996).

Figure 1. Starting position for the SJ on the force plate.

Figure 2. Vertical jump on the force plate for SJ and CMJ.

**40 m Sprint**

Sprinting ability was measured using Brower infrared timing lights at 5 m, 10 m (initial accelerations) and 40 m (total time). The warm-up consisted of running and stretching prior to the sprints. Subjects used a staggered standing start with a forward lean 0.5 m behind the start line (0 m). The displaced start (0.5 m behind the start line) was to prevent the subjects from prematurely breaking the timing beam through initial arm swings and body movements. Sprint times were recorded to accuracy of 0.01 s. Each subject was allowed two attempts at the 40 m sprint for each testing session. See Figure 3.

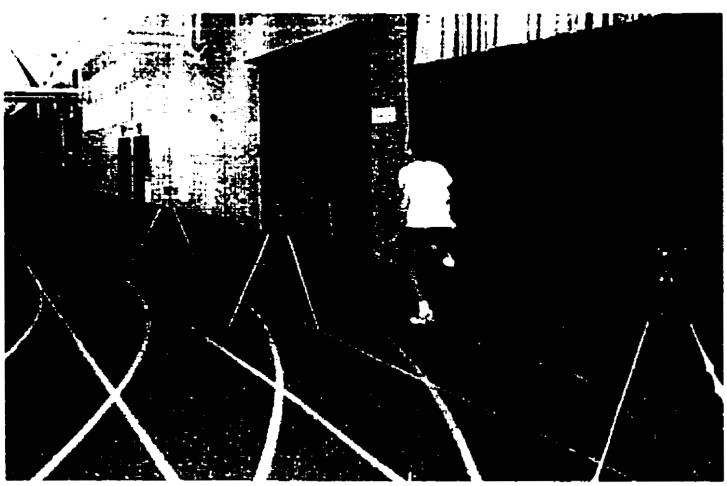

**Figure 3. Sprint test with timing lights at 0, 5, 10 and 40 m.**

**Anaerobic Power Cycle Ergometer Test**

A 7 s maximal cycle test was used to determine peak power output. Methodology for conducting the test was based upon procedures modified from Bar-Or (1987). The appropriate resistance that elicited peak power output was determined through 3, 7 s maximal cycle ergometer tests (see Figure 4). Subjects performed a 5 min warm-up on a cycle ergometer and then 5 min of stretching. The initial 7 s test resistance setting was set at 0.087 * body weight (kg) for males and 0.075 * body weight (kg) for females. Peak power output was determined by the equation described below (Bar-Or, 1987). The greatest number of pedal revolutions over a 5 s period attained during the first test was recorded and entered into the power output equation. Power was recorded in absolute (W) and relative values ($W \cdot kg^{-1}$). Typically, pedal revolutions were between 11-13 for the highest individual power outputs. The resistance was modified by increasing or decreasing the set load for the second and third trials such that the number of revolutions in 5 s period occurred between 11-13. If the subject achieved 11-13 pedal revolutions on the first trial and / or second trial, a third trial and was still conducted to ensure maximum effort was attained for each test. A minimum of 5 min was allowed for recovery between each trial. Following each trial, subjects performed an active recovery on the cycle ergometer.

Peak power output (PPO) was determined from the following equation and expressed in absolute (W) and relative ($W \cdot kg^{-1}$) values:

PPO (W) = resistance setting (kp) * number of revolutions in 5 s * 12 * 6 m * 0.1635

Where:

6 m = wheel circumference on the cycle ergometer

0.1635 = force due to gravity in 60 s

12 = factor used to equate the number revolutions in 5 s to 60 s.

**Figure 4. Anaerobic power cycle ergometer test.**

**Margaria Stairclimbing Test**

This test was used as a simple measure of anaerobic peak power taking less than a second to complete (Margaria, Aghemo & Rovelli, 1966). Each subject was allowed two attempts after their 10 min warm-up. The warm-up consisted of running, stairclimbing and stretching. Participants were required to sprint up a staircase as fast as possible 2 steps at a time. The start line was 2 m from the staircase. Times were recorded between the 8$^{th}$ and 12$^{th}$ stairs to the nearest 0.01 s. A switch mat was placed on the 8$^{th}$ stair and a set of Brower infrared timing lights on the 12th stair. See Figure 5. Power was calculated by the equation: $P = WT * 9.81\ m \cdot s^{-2} * D \cdot t^{-1}$.

Where:

P = power in watts (W)

WT = weight of the subject (kg)

$9.81\ m \cdot s^{-2}$ = force of gravity

D = vertical displacement between the 8th and 12th stairs (cm)

t = time (s) taken to step between the 8th and 12th stairs as measured by the switch mat and timing lights.

**Figure 5. Margaria Stairclimbing test using timing lights on the 8th and 12th stairs.**

**Maximal Back Squat (1 RM)**

The 1 RM test was conducted with free weights as described by Stone and O'Bryant (1987); Simpson, Rozenek and Garhammer (1997); and Elliott, Wilson and Kerr (1989). The 1 RM back squat was primarily used to determine the appropriate training intensities for each training group in addition to assessing leg strength. The use of maximum strength testing for the purpose of determining training intensities has been used in similar studies requiring exact load settings for specific training programs (Lyttle et al., 1996; Baker et al., 1994; and Willoughby, 1993). Determination of 1 RM squat was essential to this study since the MxS group trained at intensities of 85-90% of 1 RM and the MxP group trained at an exact intensity of 30% of 1 RM.

Repetition maximum strength values were determined progressively over 5-6 sets of back squats for the training groups. The squat depth was initially determined by having each subject squat to the level whereupon their thighs were parallel to the floor. Once the depth level was measured, safety bars were inserted into the squat rack to mark that position. Subjects performed the loaded movements under the direction of the test administrator. The warm-up consisted of performing squats of approximately 50% of perceived maximum for 10 repetitions and at 75% of perceived maximum for 3-5 repetitions. Once the warm-up was complete, attempts were made at 80%, 95% and 100% of perceived maximum for one repetition. An additional set was attempted at a load of 105% of estimated maximum if the 100% effort was attained. Each of the attempts from 80-105% of perceived maximum was only performed if the preceding attempt was successful (Elliott et al., 1989). Subjects had to perform the lifts to the parallel squat level in order to be successful. Close attention was given to subject's personal opinion regarding how close they were to attaining their 1 RM, as loads progressively became heavier (Kraemer & Fry, 1995). Communication between the test administrator and subject was emphasized during the 1 RM testing. A minimum of 5 min was allowed for rest between each set. See Figure 6.

The squat movement required the subjects to slowly descend until their thighs were parallel to the floor upon which a verbal signal was given to ascend back to the starting position. Three experienced spotters were used at all times; one on each side of the barbell ends and one directly behind the subject. The rear spotter remained in contact with the subject throughout the entire range of motion for the parallel squat (see Figure 6). If the subject was unable to lift the set load during the initial ascent of the lift, they were immediately told to set the bar down on the safety bars, which were located at the parallel squat level. However, if the subject was able to lift the heavy load but had difficulty completing the movement to the upright position, spotters provided immediate assistance. Due to the inexperience with performing the squat movement and the possible risk of injury within the control group, a predicted 1 RM squat protocol of 6-8 repetitions was used. The predicted 1 RM value was determined using a similar progressive procedure of 5-6 sets as previously described. Predicted strength values were derived off a normative table (Baechle, 1994). Spotters and feedback were also used at all times.

**Figure 6. Maximal back squat with rear spotter.**

## Training Intervention

All required procedures, and potential risks associated with participating in the present study, were explained to the subjects prior to the training intervention. Participants were made aware that they had the right to terminate their participation in the experiment at will and that the privacy and confidentiality of their results would be maintained at all times. However, participants were also advised that the investigators of this study reserved the right to terminate their involvement at any time. Results of the study will be stored for five years in a locked cabinet in room B268 at the Faculty of Kinesiology, University of Calgary.

## Training Programs

Participants were randomly assigned to one of two training groups, maximum strength and plyometrics (MxS) and maximum power and plyometrics (MxP). The training occurred two days per week for a period of eight weeks for both the training and control groups. Two to three days of rest were allocated between each training session for all groups (i.e. Monday - Thursday or Tuesday - Friday). The volume of training was only partially equated due to the difference in training methodologies. However, the total number of sets performed for each group was equated similar to the Baker et al. (1994) study.

**Maximum Power and Plyometric Training (MxP)**

The MxP group consisted of two training phases. In the first phase (weeks 1-4), subjects performed progressive ballistic jump squats. The second phase (weeks 6-9) consisted of a reduced volume of jump squats and the introduction of plyometric exercises into the training sessions. Ballistic jump squats were performed with 30% of 1 RM as determined from the testing sessions. Each set consisted of 8 repetitions of maximum effort (Lyttle et al., 1996). Sets progressed from 4-7 over the initial 4 week training period. Jump squats were reduced to 2 sets per session for weeks 6-9. The volume of jump squats was reduced in order to focus on the high velocity training in the second phase of the study. Hoffman, Maresh, Armstrong and Kraemer (1991) discovered that resistance training consisting of two sessions per week was sufficient to maintain strength. In addition, Bompa (1994) suggested that for the maintenance of strength, athletes should be training 2-3 sessions per week of 2-4 sets per exercise.

One to two warm-up exercises of body weight jump squats and stretching were performed prior to each training session. The degree of knee flexion was determined from the depth the subject lowered to in the 1 RM parallel squat (thighs parallel to the floor). Each jump squat was subsequently performed to the depth measured in the parallel 1 RM squat. Training load was slightly increased, as subjects became stronger with training. Constant feedback between the trainer and subject was used as the governing tool for increasing the training load. The safety bars were set 30 cm below the parallel squat height to prevent the load from striking the safety bars on the downward phase of the jump squat. Spotters were used at all times. See Figure 7.

The plyometric training portion of phase two was integrated at week 6 and progressively increased in volume through week 9. Plyometric exercises consisted of horizontal and vertical bounding movements as well as depth jumps as seen in Table 1 and Figures 8-12. All participants performed a routine 10-15 min warm-up consisting of jogging, stretching and a 30 m sprint (Bompa, 1996). Participants were encouraged to have minimal contact time (amortization phase) with the ground upon each landing by contracting the leg extensors as rapidly as possible. Depth jumps were executed by having the subject drop from the box and upon landing immediately jump vertically as rapidly as possible (Bompa, 1996; Holcomb et al., 1996; and Bobbert, 1990). Plyometric exercises were performed before the ballistic jump squats in weeks 6-9. The order of training was completed in this manner since explosive SSC movements should be performed in a rested state (Bompa, 1996). Two to three days of rest was allotted between each training session to allow for sufficient recovery. Nicol, Komi and Horita (1996) discovered that the stretch-reflex sensitivity was reduced until two days after an exhaustive plyometric workout, which was attributed to muscle damage. See Table 1 for program details.

**Table 1. Maximum power and plyometric program (MxP)**

| Week | Days | Jump Squats @ 30% 1RM | Rest / set | Total reps / day |
|---|---|---|---|---|
| 0 | | test | test | test |
| 1 | 1&2 | 4 sets X 8 reps | 2-3 min | 32 |
| 2 | 1&2 | 5 sets X 8 reps | 2-3 min | 40 |
| 3 | 1&2 | 6 sets X 8 reps | 2-3 min | 48 |
| 4 | 1&2 | 7 sets X 8 reps | 2-3 min | 56 |
| 5 | | test | test | test |
| 6 | 1&2 | 2 sets X 8 reps | 2-3 min | 16 |
| 7 | 1&2 | 2 sets X 8 reps | 2-3 min | 16 |
| 8 | 1&2 | 2 sets X 8 reps | 2-3 min | 16 |
| 9 | 1&2 | 2 sets X 8 reps | 2-3 min | 16 |
| 10 | | test | test | test |
| | | | | 240 |

| Week | Days | Plyometric Exercises | | |
|---|---|---|---|---|
| 5 | | test | test | test |
| 6 | 1&2 | 3 Exercises X 2 sets X 12 reps | 3-4 min | 72 |
| 7 | 1&2 | 3 Exercises X 3 sets X 12 reps | 3-4 min | 108 |
| 8 | 1&2 | 3 Exercises X 3 sets X 12 reps | 3-4 min | 108 |
| 9 | 1&2 | 3 Exercises X 3 sets X 12 reps | 3-4 min | 108 |
| 10 | | test | test | test |
| | | | | 396 |

| Week | Days | Plyometric Exercise Description |
|---|---|---|
| 6 | 1&2 | High Knee Tucks, Split Squats, Alternate Leg Bounds |
| 7 | 1&2 | Single Leg Hops, Alternate Leg Bounds, Hori. Box Hops (Double leg bounding) |
| 8 | 1&2 | Single Leg Hops, Alternate Leg Bounds, Hori. Box Hops |
| 9 | 1&2 | Lateral Cone Hops, Alternate Leg Bounds, Hori. Box Hops |

| Week | Days | Depth Jumps | | |
|---|---|---|---|---|
| 5 | | test | test | test |
| 6 | 1&2 | 30cm X 2 sets X 8 reps | 4-5 min | 16 |
| 7 | 1&2 | 40cm X 3 sets X 8 reps | 4-5 min | 24 |
| 8 | 1&2 | 50cm X 3 sets X 8 reps | 4-5 min | 24 |
| 9 | 1&2 | 60cm X 3 sets X 8 reps | 4-5 min | 24 |
| 10 | | test | test | test |
| | | | | 88 |

| | | | |
|---|---|---|---|
| **Total Sets:** | **52** | **Total Reps:** | **724** |
| 2 days / week: | 104 | 2 days / week: | 1448 |

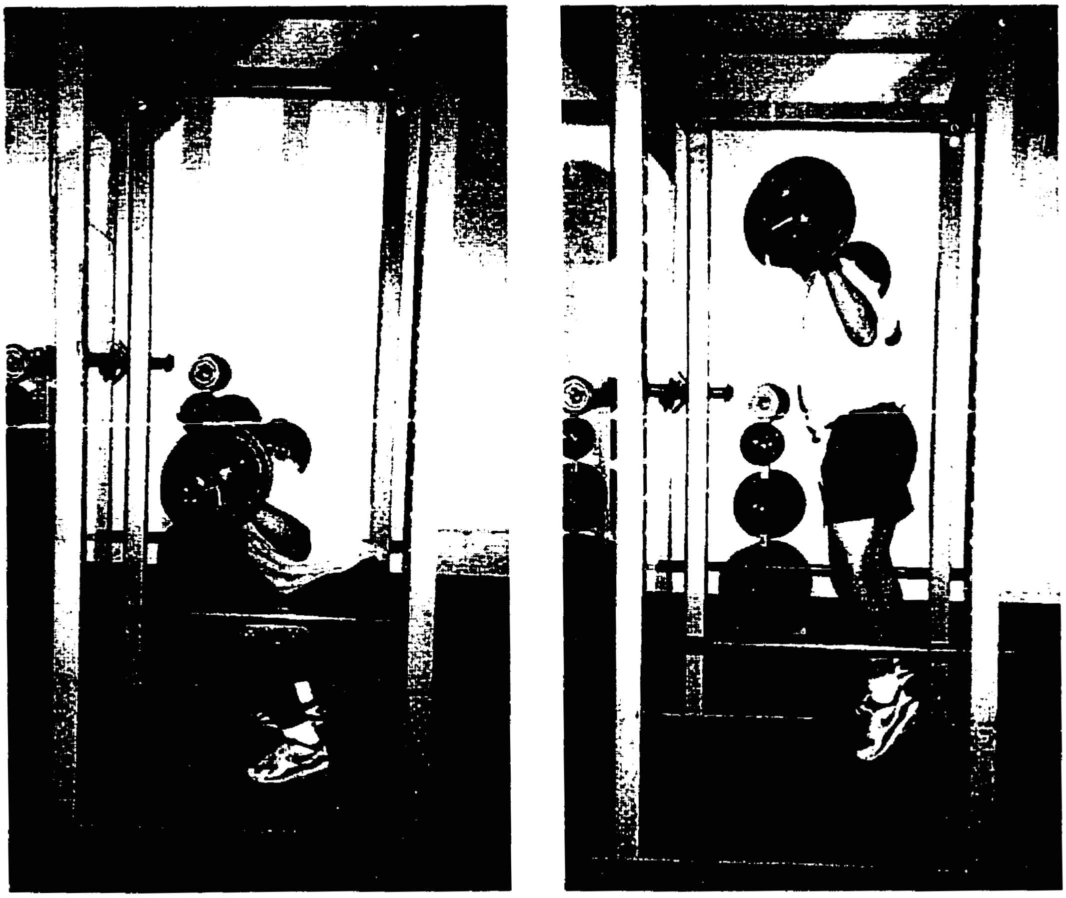

Figure 7. Start and finish of the ballistic jump squat at 30% of 1 RM.

Figure 8. Horizontal plyometrics. Alternate leg bounds.

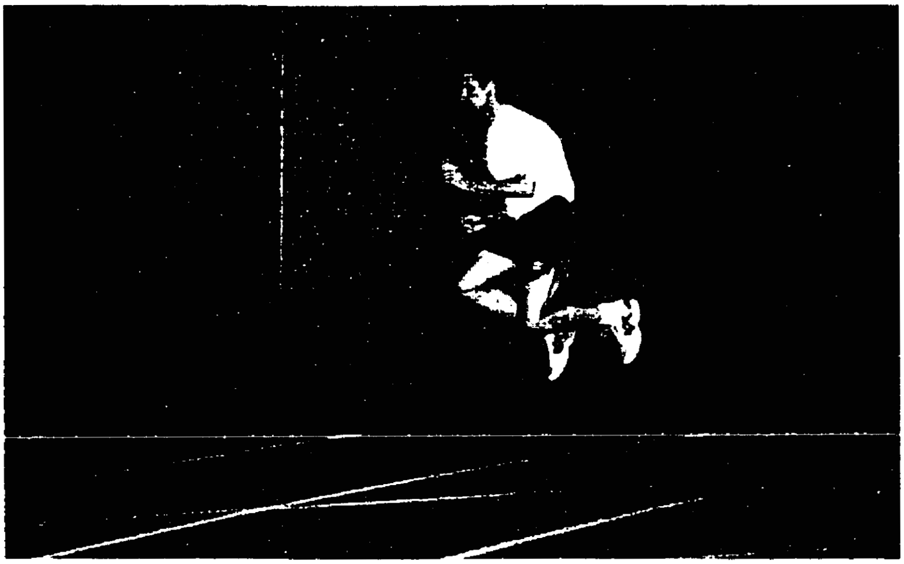

Figure 9. Horizontal plyometrics. Single leg hops.

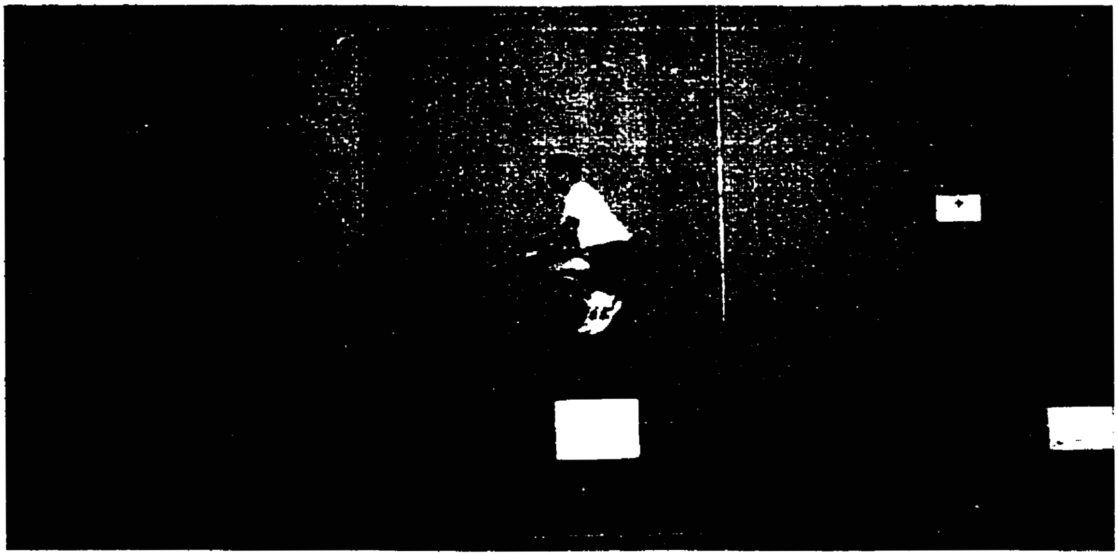

Figure 10. Horizontal plyometrics. Double leg bounds over boxes.

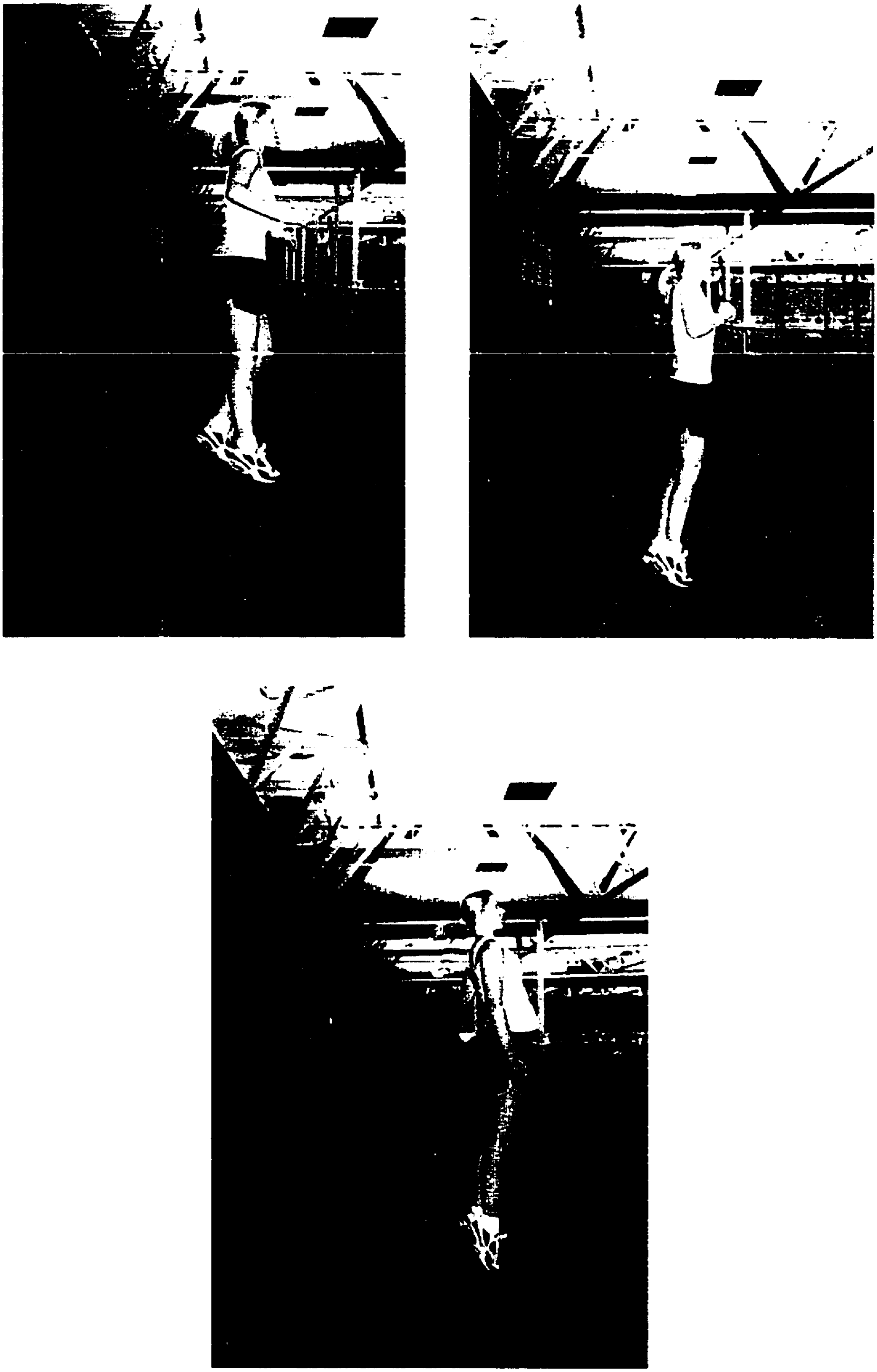

**Figure 11. Vertical plyometrics. Depth jumps progressing from the start, ground contact and immediately into the vertical jump.**

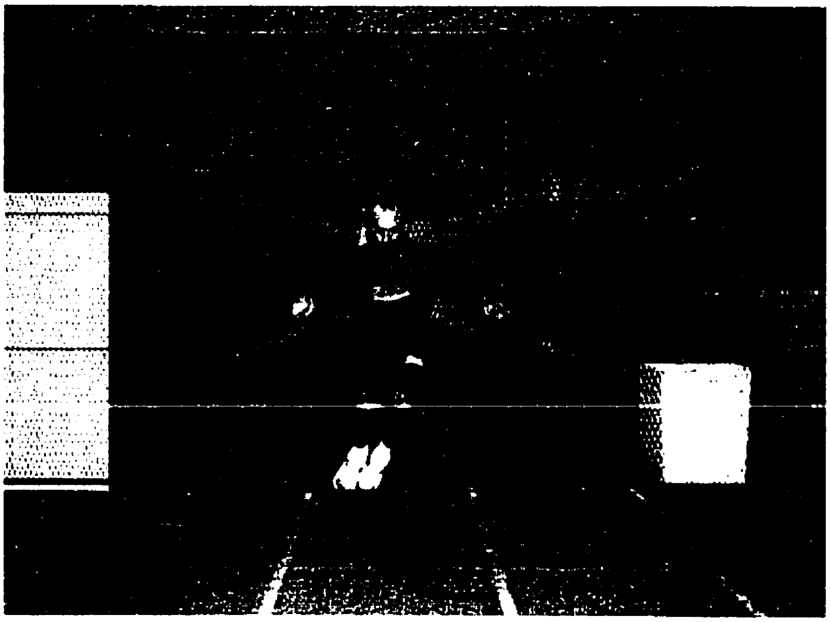

**Figure 12. Vertical plyometrics. Lateral cone hops.**

**Maximum Strength and Plyometric Training (MxS)**

Maximum strength training predominantly occurred during the first 4 weeks of training. The resistance used was 85-90% of 1 RM as determined from the testing sessions. The training volume increased from 4-7 sets of 4-6 repetitions for the initial 4 week period. Volume of training was reduced to 2 sets per training session to maintain strength for weeks 6-9, similar to the MxP group (see Table 2). The degree of knee flexion was determined from the depth the subject lowered to in the 1 RM parallel squat (thighs parallel to the floor). Subjects performed 1-2 sets of sub-maximal warm-up squats and then the specified number of sets all at 85-90% of 1 RM. If the subjects were able to do more or less than the prescribed repetitions, the training load was changed accordingly to ensure subjects were training with the appropriate intensity. Spotters and safety bars were used at all times.

The second phase of the study, weeks 6-9, consisted of a reduced volume of MxS training and the incorporation of plyometric training as seen in Table 2. Plyometric training was identical to the MxP group (See Figures 8-12). The plyometric exercises were also performed prior to the MxS squats.

**Table 2. Maximum strength and plyometric program (MxS)**

| Week | Days | MxS Back Squats | Rest / set | Total reps / day |
|---|---|---|---|---|
| 0 | | test | test | test |
| 1 | 1&2 | 4 sets X 4-6 reps | 3-4 min | 20 @ 5 reps |
| 2 | 1&2 | 5 sets X 4-6 reps | 3-4 min | 25 |
| 3 | 1&2 | 6 sets X 4-6 reps | 3-4 min | 30 |
| 4 | 1&2 | 7 sets X 4-6 reps | 3-4 min | 35 |
| 5 | | test | test | test |
| 6 | 1&2 | 2 sets X 4-6 reps | 3-4 min | 10 |
| 7 | 1&2 | 2 sets X 4-6 reps | 3-4 min | 10 |
| 8 | 1&2 | 2 sets X 4-6 reps | 3-4 min | 10 |
| 9 | 1&2 | 2 sets X 4-6 reps | 3-4 min | 10 |
| 10 | | test | test | test |
| | | | | 130 |
| **Week** | **Days** | **Plyometrics Exercises** | | |
| 5 | | test | test | test |
| 6 | 1&2 | 3 Exercises X 2 sets X 12 reps | 3-4 min | 72 |
| 7 | 1&2 | 3 Exercises X 3 sets X 12 reps | 3-4 min | 108 |
| 8 | 1&2 | 3 Exercises X 3 sets X 12 reps | 3-4 min | 108 |
| 9 | 1&2 | 3 Exercises X 3 sets X 12 reps | 3-4 min | 108 |
| 10 | | test | test | test |
| | | | | 396 |
| | | **Plyometric Exercise Description** | | |
| 6 | 1&2 | High Knee Tucks. Split Squats. Alternate Leg Bounds | | |
| 7 | 1&2 | Single Leg Hops. Alternate Leg Bounds. Hori. Box Hops (Double leg bounding) | | |
| 8 | 1&2 | Single Leg Hops. Alternate Leg Bounds. Hori. Box Hops | | |
| 9 | 1&2 | Lateral Cone Hops. Alternate Leg Bounds. Hori. Box Hops | | |
| **Week** | **Days** | **Depth Jumps** | | |
| 5 | | test | test | test |
| 6 | 1&2 | 30cm X 2 sets X 8 reps | 4-5 min | 16 |
| 7 | 1&2 | 40cm X 3 sets X 8 reps | 4-5 min | 24 |
| 8 | 1&2 | 50cm X 3 sets X 8 reps | 4-5 min | 24 |
| 9 | 1&2 | 60cm X 3 sets X 8 reps | 4-5 min | 24 |
| 10 | | test | test | test |
| | | | | 88 |

| | | | |
|---|---|---|---|
| **Total Sets:** | **52** | **Total Reps:** | **614** |
| 2 days / week: | 104 | 2 days / week: | 1228 |

**Figure 13. Maximum strength squat lowering towards the parallel level.**

**Control Group**

The participants in the control group (CT) were asked to maintain their regular levels of physical activity and soccer throughout the 10 week study.

**Core Stability**

All groups, MxP, MxS and CT, performed core stability exercises for the abdominal and lower back musculature at the end of each training session. The purpose of core stability training was to prevent injury of the lower trunk area from the intensive training regime. Training the core area has been demonstrated as an essential form training for individuals and athletes (Baker et al., 1994). Specific exercises were performed to train the anterior muscles of the abdominal wall and the posterior muscles of the vertebral column. These muscles included the rectus abdominis, external and internal obliques, transverse abdominis, quadratus lumborum and the erector spinae. One exercise for each core area of various forms was performed after each training session throughout training weeks 1-4 and 6-9.

**Supplementary Training Program Information**

Participants were asked to maintain and document their regular activities during the 10 week study, including their standard training exercises. Participants were also required to abstain from additional lower body resistance training that was not a part of this training intervention. In addition, participants were required not to engage in any new forms of sprint or all-out exercise. This limitation was enforced since additional high intensity training could have affected a number of the performance tests in this study. All training sessions were fully supervised by the author of this study and training diaries were maintained for each subject.

**Statistical Analysis**

Prior to statistical analysis, the assumptions of normality and equal variance regarding the sample data were tested. The Kolmogorov – Smirnov Goodness of Fit Test and normal quantile plots were used to the test the normality of the data. The homogeneity of variance of the sample data was assessed using residual plots.

A one-way analysis of variance (ANOVA) for the variables: CMJ, SJ, 40 m sprint time (5, 10, and 40 m intervals), anaerobic power cycle test, Margaria stairclimb and the 1 RM squat. At the completion of the study, a 2 (group) by 3 (time) ANOVA with repeated measures on one factor (time) at the pre, mid and post experiment testing sessions was conducted between the two training groups (MxP & MxS). A 3 (group) by 2 (time) ANOVA was also performed since the control group was only available to test at the pre and post sessions during the study. Tukey's post hoc test was used to assess any interaction effects revealed by the ANOVA's. Significance was set at an alpha level of 0.05. The software used for the statistical analysis was SPSS version 9.0 (SPSS Inc., Chicago, IL).

# CHAPTER FOUR

## RESULTS

The compliance in the study was 92.2% for the scheduled supervised training sessions. There were no training related injuries for male or female subjects. The mean ages for the MxS, MxP and CT groups were 22.25 ± 4.49 yrs, 23.65 ± 3.43 yrs and 25.50 ± 3.94 yrs, respectively. The mean mass for the MxS, MxP and CT groups were 76.14 ± 12.98 kg, 77.85 ± 16.87 kg and 59.60 ± 3.76 kg, respectively. Demographic information based upon gender for age and mass can be seen in Table 3. The athletic and training background of the participants can be seen in Table 4.

**Table 3. Subject characteristics for males and females.**

| | **Male** | **Age (yr)** | | **Mass (kg)** | |
|---|---|---|---|---|---|
| | *n* | *Mean* | *SD* | *Mean* | *SD* |
| **MxS** | 7 | 22.89 | 5.01 | 84.16 | 12.49 |
| **MxP** | 9 | 24.50 | 4.29 | 88.78 | 10.68 |

| | **Female** | **Age (yr)** | | **Mass (kg)** | |
|---|---|---|---|---|---|
| | *n* | *Mean* | *SD* | *Mean* | *SD* |
| **MxS** | 7 | 21.42 | 4.43 | 65.83 | 4.14 |
| **MxP** | 6 | 22.43 | 1.62 | 62.24 | 7.77 |
| **Control** | 6 | 25.50 | 3.94 | 59.60 | 3.76 |

**Table 4. Athletic and training background of the participants**

| **Number of Indivduals** ($n$ = 39) | | |
|---|---|---|
| **Male** ($n$ = 17) | **Female** ($n$ = 22) | **Sport** |
| 1 | 3 | University Hockey |
| 6 | 2 | Jr. A level Hockey |
| | 1 | Figure Skating |
| 2 | | Provincial Snow Boarding |
| 1 | 1 | Baseball |
| | 3 | Endurance Training (Cycle / Run) |
| | 1 | Triathalon |
| | 1 | Synchronized Swimming |
| 1 | | University Gymnastics |
| | 2 | Rugby |
| 1 | | Mountain Bike Racing |
| 1 | | Volleyball |
| 1 | | Track (Sprints) |
| | 1 | Modern Dance |
| | 1 | Aerobics Instructor |
| 3 | | Weight Training |
| | 6 | Senior Women's Soccer (control group) |

Prior to commencement of training, a one-way ANOVA revealed a significant ($p < 0.05$) difference for the CMJ between the three experimental groups. Further analysis revealed that the maximum strength (MxS) and maximum power (MxP) groups had greater pre-test CMJ scores than the control (CT) group. After ten weeks of training, significant ($p < 0.05$) within group results for the MxS and MxP groups were identified in selected measures. The MxP group significantly improved their SJ, stairclimbing power, cycle power and squat strength, whereas the MxS group only improved their stairclimbing power and squat strength. Although the MxS group did not improve their cycle power and SJ, no between group differences between MxS and MxP were detected for any of the performance measures. However, significant differences ($p < 0.05$) were discovered between the CT and training groups (MxS and MxP) at the post testing session for the measures CMJ, SJ, cycle power and 1 RM squat as detected by the 3 (group) X 2 (time) ANOVA. The overall results of this study can be seen in Table 5.

**Table 5. Group performance scores over ten weeks.**

| Variable | Test | MxS, $n$ = 14 *Mean* | *SD* | MxP, $n$ = 15 *Mean* | *SD* | CT, $n$ = 6 *Mean* | *SD* |
|---|---|---|---|---|---|---|---|
| 5 m Sprint | Pre | 0.80 | 0.12 | 0.82 | 0.13 | 0.79 | 0.03 |
| time (s) | Mid | 0.79 | 0.06 | 0.78 | 0.06 | | |
| | Post | 0.77 | 0.05 | 0.76 | 0.05 | 0.79 | 0.03 |
| 10 m Sprint | Pre | 1.90 | 0.14 | 1.87 | 0.11 | 1.96 | 0.07 |
| time (s) | Mid | 1.92 | 0.16 | 1.89 | 0.10 | | |
| | Post | 1.91 | 0.12 | 1.86 | 0.08 | 1.95 | 0.05 |
| 40 m Sprint | Pre | 5.98 | 0.62 | 5.83 | 0.47 | 6.12 | 0.23 |
| time (s) | Mid | 6.00 | 0.64 | 5.83 | 0.43 | | |
| | Post | 6.01 | 0.55 | 5.79 | 0.41 | 6.14 | 0.15 |
| Static Jump | Pre | 0.29 | 0.08 | 0.28 | 0.05 | 0.22 | 0.05 |
| height (m) | Mid | 0.30 | 0.06 | 0.31 | 0.06 | | |
| | Post | 0.29 | 0.05 | ^0.32 | 0.06 | 0.23 | 0.04 |
| Counter Movement Jump | Pre | 0.34 | 0.09 | 0.34 | 0.05 | 0.24 | 0.04 |
| height (m) | Mid | 0.33 | 0.07 | 0.35 | 0.06 | | |
| | Post | 0.33 | 0.07 | 0.35 | 0.07 | 0.26 | 0.04 |
| Cycle Power | Pre | 10.29 | 1.52 | 10.50 | 1.48 | 9.38 | 0.81 |
| ($W.kg^{-1}$) | Mid | 10.91 | 1.81 | 11.36 | 1.61 | | |
| | Post | 11.50 | 1.73 | ^12.17 | 1.56 | 10.20 | 0.79 |
| Stair Climbing Power | Pre | 23.36 | 3.63 | 22.53 | 4.53 | 20.28 | 4.73 |
| ($W.kg^{-1}$) | Mid | 25.79 | 3.12 | 25.29 | 2.97 | | |
| | Post | ^26.28 | 2.63 | ^26.08 | 2.82 | 23.74 | 2.40 |
| † Squat Strength - 1 RM | Pre | 1.30 | 0.32 | 1.36 | 0.24 | 1.09 | 0.11 |
| ($kg.BW^{-1}$) | Mid | *1.75 | 0.32 | *1.69 | 0.29 | | |
| | Post | ^1.90 | 0.30 | ^1.87 | 0.29 | 1.21 | 0.13 |

Statistical significance ($p < 0.05$) is denoted by * for pre to mid testing session and ^ for pre to post testing.
† for squat strength denotes that the control group used a predicted 1 RM protocol.

**Vertical Jump Tests on Force Plate**

***Static jump (SJ)*** A one-way ANOVA conducted at the pre–test session detected a difference in SJ height between the three groups, however the difference only approached significance ($p = 0.094$). The 3 (group) X 2 (time) ANOVA revealed a significant group X time interaction. Subsequent post - hoc analysis demonstrated that the MxP group had a greater post-test SJ height than the CT group. The MxP group improved ($p < 0.05$) their SJ height by 12.5% from pre to post testing sessions as seen in Table 5 and Figure 14 (pre: 0.28 ± 0.05, post: 0.32 ± 0.06 m). No significant changes were observed for the MxS and CT groups over time.

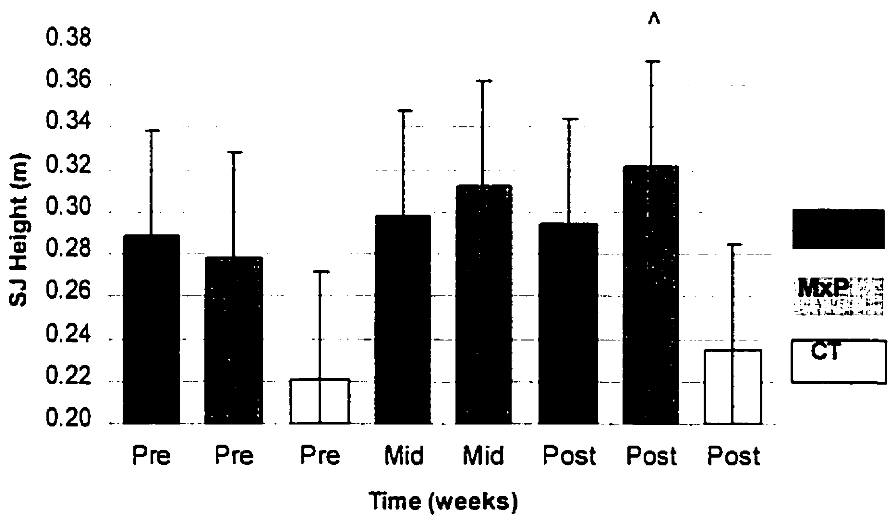


**Figure 14. Static jump height for all groups from pre to post training. Statistical significance ($p < 0.05$) within the MxP group is denoted by ^ (pre to post).**

***Counter movement jump (CMJ)*** There were no significant differences between and within MxP and MxS groups over time. However, the pre-test one-way ANOVA revealed the MxS and MxP groups had significantly ($p < 0.05$) greater CMJ heights than the CT group. At the end of the study, the MxS and MxP groups continued to have a greater ($p < 0.05$) CMJ height than the CT group as detected by the 3 (group) X 2 (time) ANOVA. However, no significant improvement in CMJ height was detected over time for all three groups as seen in Table 5.

**Cycle Power Test**

A significant group X time interaction was detected by the 3 X 2 ANOVA. Further analysis revealed that the MxP group improved ($p < 0.05$) their cycle power by 15.90% from pre to post training as seen in Figure 15 (pre: 10.50 ± 1.48, post 12.17 ± 1.56 $W \cdot kg^{-1}$). The post result was significantly ($p < 0.05$) greater for the MxP group in comparison to CT group. No significant improvements in cycle power were detected for the MxS and CT group over time as seen in Table 5.

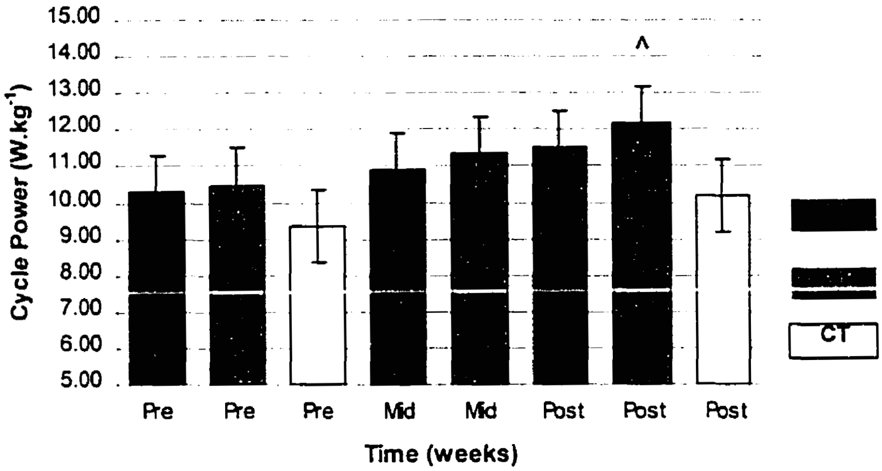


**Figure 15. Changes in peak cycle power for all groups over time. Statistical significance ($p < 0.05$) within the MxP group is denoted by ^ (pre to post).**

## Margaria Stairclimbing Test

Both training groups significantly ($p < 0.05$) increased their stairclimbing power from pre to post training as detected by 3 (group) X 2 (time) ANOVA. The MxS group improved by 12.50% (pre: 23.36 ± 3.63, post: 26.28 ± 2.63 $W{\cdot}kg^{-1}$) while the MxP group improved by 15.76% (pre: 22.53 ± 4.53, post: 26.08 ± 2.82 $W{\cdot}kg^{-1}$) as seen in Figure 16. The CT group also improved their stairclimbing power by 17.06% (pre: 20.28 ± 4.73, post: 23.74 ± 2.40 $W{\cdot}kg^{-1}$), however this difference was not significant from pre to post testing sessions. There were no significant differences in stairclimb power between all three groups over time.

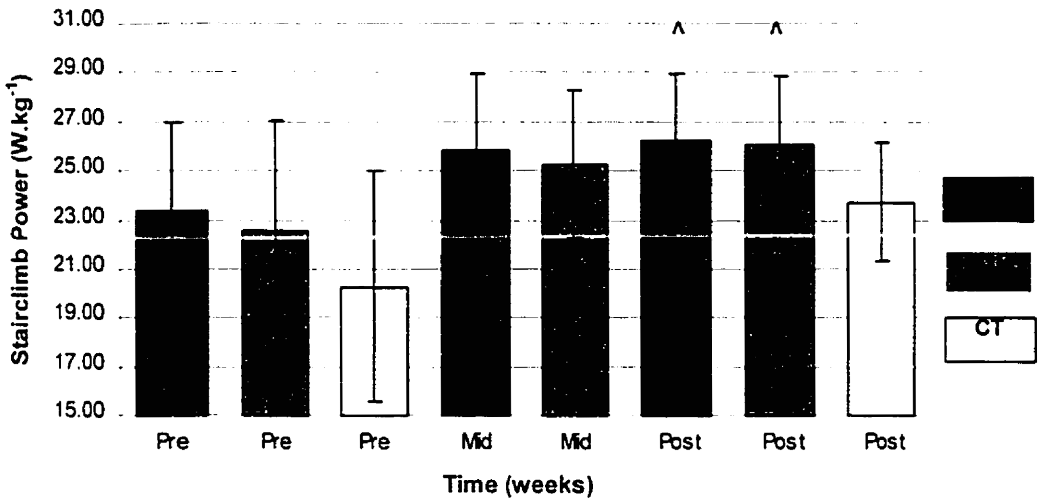


**Figure 16. Changes in stairclimbing power for all three groups. Statistical within group significance ($p < 0.05$) is denoted by ^ (pre to post).**

## Sprints (5, 10, 40 m)

No significant interaction between group and time for the 5 m, 10 m and 40 m sprints were detected by the ANOVA. However, the MxP group did make a minor of improvement ($p > 0.05$) of 7.32% in the 5 m acceleration time as seen in Table 5.

## Squat Strength - 1 RM

A significant group X time interaction was discovered by the two-way ANOVA. The 1 RM squat (relative to body weight) increased from pre to mid training ($p < 0.05$) by 34.62% for the MxS group (pre: 1.30 ± 0.32, mid: 1.75 ± 0.32 kg·$BW^{-1}$) and 24.26% for the MxP group (pre: 1.36 ± 0.24, mid: 1.69 ± 0.29 kg·$BW^{-1}$). Overall, from pre to post training, the MxS group improved ($p < 0.05$) by 46.15% (post: 1.90 ± 0.30 kg·$BW^{-1}$)

while the MxP group improved by 37.50% (post: $1.87 \pm 0.29$ kg·BW$^{-1}$) as seen in Figure 17. No significant changes were observed from mid to post testing sessions. The CT slightly improved their predicted 1 RM squat strength from pre to post by 11.01%, however, this change was not significant over time. The pre to post increases in lower body strength for both training groups were significantly ($p < 0.05$) greater in comparison to the predicted 1 RM for the CT group as seen in Table 5.

Squat strength was also evaluated on an absolute scale. The MxS group significantly ($p < 0.05$) increased their overall load lifted between pre, mid and post training. However, the MxP group only increased the absolute load from pre to post training as seen in Figure 18.

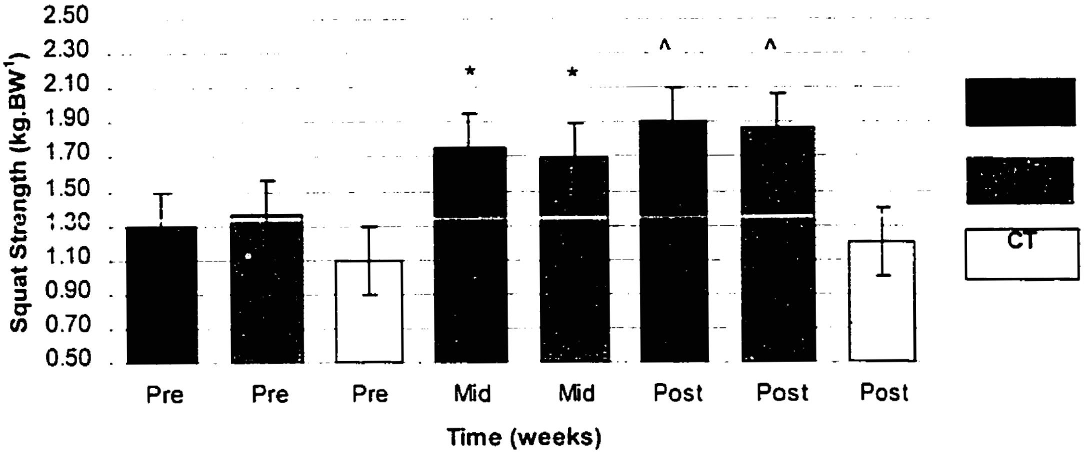


**Figure 17. Relative squat strength improvement for all groups over time. Statistical within group significance ($p < 0.05$) is denoted by * (pre to mid) and ^ (pre to post).**

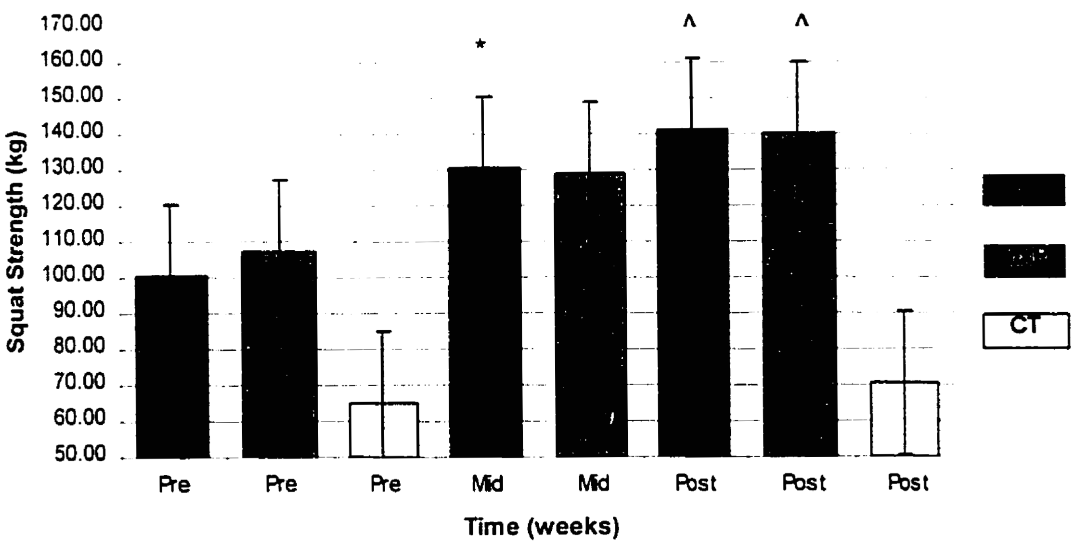


**Figure 18. Absolute squat strength improvement for all groups over time. Statistical within group significance ($p < 0.05$) is denoted by * (pre to mid) and ^ (pre to post).**

# CHAPTER FIVE

## DISCUSSION

It was hypothesized that the combined ballistic jump squat and plyometric (MxP) training would be more effective at performance related tasks than the combined maximum strength and plyometric (MxS) training program. However, the results of the present study suggest that both groups were equally effective at performing the static jump, cycle power and stairclimbing power over 10 weeks. The second hypothesis stated that both training groups would improve to a similar extent in squat strength, despite the difference in training methods between MxS and MxP groups. The second prediction was shown to be correct as both groups significantly improved their lower body strength over time. The MxS training method was effective at significantly improving stairclimbing power and squat strength. Although the MxP group improved their cycle power and static jump whereas the MxS group reported no changes, no significant differences in those same variables were discovered between groups. These results suggest that at the post test time, ballistic jump squat training (MxP) is as equally effective as traditional methods of training (MxS) for enhancing lower body power as well as increasing strength.

### Static Jump

The MxP group improved their SJ height by 12.5% in comparison to the MxS group who demonstrated no improvement over time. Although, no significant group effect was detected, these results were similar to Wilson et al. (1993) who discovered that maximum power training improved 12.9% in the SJ while the high resistance group improved their SJ by 5.9%. However, Lyttle et al. (1996) discovered that when plyometrics were combined with high resistance training and then compared to maximal power training, both groups improved to the same extent (18.6% vs. 19.8%). It was expected that the MxS group in the present study would also show similar improvement as the combined group in the Lyttle et al., (1996) study. One possible explanation for lack of improvement for the MxS group may be due to the difference in testing methodology between studies. Lyttle et al. (1996) used a Vertec (Sports Imports Inc., Columbus, Ohio) vertical jump instrument, which allows subjects to use their arms while jumping to displace a marker overhead. The advantage of using the Vertec is that a realistic form of jumping is used. Subjects in this study were required to place their hands on their hips throughout the entire jump while subjects in the Wilson et al. (1993) study held a bar on their shoulders. Therefore, upper torso / arm action did not occur for subjects in the present study and the Wilson et al. (1993) study, which may explain the similar lack of improvement in comparison to the Lyttle et al. (1996) study. In a review of effective training modes, Morrissey, Harman, and Johnson (1995) stated that the greatest training effects have been demonstrated when tests were of the same exercise-type as the training programs. Subjects in the present study were allowed and encouraged to use arm actions throughout the 4 weeks of plyometric training, however arm actions were prohibited during testing.

Despite the limitations of the vertical jumping procedure used in the present study, the MxP group still managed to improve within group performance. This may be attributed to the nature of performing loaded jump squats, which requires subjects to hold a bar on their shoulders throughout the entire range of motion inhibiting arm involvement. Therefore, the vertical jump test on the force plate may have been more applicable and specific to the MxP group in comparison to the MxS group.

**Countermovement Jump**

The countermovement jump showed no improvement over the course of the present study for both the training and CT groups. These results were similar to Newton, Kraemer and Häkkinen (1999) who did not find any improvements in flight time or jump height using a force plate. Newton et al. (1999) suggested that the jump and reach test using a Vertec is the most appropriate test to measure improvements in vertical jump. Although the force plate is effective at deriving information such as force output, impact at landing, flight time and rate of force development, these variables are primarily used to explain or identify adaptations (Newton et al., 1999). Contrary to this study, Wilson et al. (1993) and Lyttle et al. (1996) demonstrated significant improvements for all the training groups in the CMJ test. The lack of improvement in the present study may be due to the lack of specificity of the vertical jump test. Wilson et al. (1993) performed the CMJ test using the Plyometric Power System (PPS) (Optimal Kinetics, Lismore, Australia) to measure jump height. The PPS machine was also used to train the subjects and therefore, the CMJ test was very similar to the training method. Moreover, Lyttle et al. (1996) used a Vertec to measure CMJ, which is the most specific method of testing vertical jumping ability as previously stated. It is possible that the lack of improvement for both groups in this study may be due to the poor specificity of the CMJ test.

**Cycle Power**

The MxP group demonstrated a significant improvement over time in the cycle power test. Although the MxS group did not significantly improve their cycle power to the extent of the MxP group, both groups displayed similar results as found in the Wilson et al. (1993) and Lyttle et al. (1996) studies. Wilson et al. (1993) discovered that the MxP power group improved by 5.2% while the weight-training group improved by 6.5%. These results are similar to the pre to mid testing sessions in the present study, where the MxP and MxS group improved by 8.19% and 6.03%, respectively. However, the incorporation of plyometric training from mid to post training appears to have further enhanced cycle power for the MxP and MxS group by 15.9% and 11.75%. This improvement was most evident for the MxP group as the change was significantly greater from pre to post testing. Thus the high velocity plyometric exercises may be applicable to cycling power and hence contribute to a high rate of muscular contraction.

The development of strength prior to shifting into plyometric training appears to be a necessary prerequisite. Wilson et al. (1993) discovered that the plyometric-only group, who did not perform any ballistic or heavy strength training, also did not improve cycling power from pre to post testing. However, the strength training methods used predominantly in the first phase of the present study, especially for the MxP group, provided the subjects with the necessary strength to quickly improve cycle power. This further supports the concept of strength development prior to power training.

Lyttle et al. (1996) demonstrated improvements in cycle power for the maximal power group and combined resistance training and plyometric group of 9.0% and 7.8%, respectively, over eight weeks. These results are similar to the pre to mid testing results over four weeks in the present study. Since the training groups in the present study displayed similar improvements to the Lyttle et al. (1996) study in a shorter period of time, sufficient training volume also becomes an important factor. Lyttle et al. (1996) only used depth jumps for SSC enhancement, whereas the plyometric program in the present study also included bounding and box jumping exercises implying that more than one form of plyometric exercise may be needed to maximize improvement in cycling power.

**Stairclimb Power**

The MxS and MxP training groups significantly improved their stairclimbing ability over the course of the present study by 12.50% and 15.76%, respectively. Although the 17.06% improvement in stairclimb power by the CT group was not significant over time due to a Type II statistical error, this change indicates that improvement by the MxS and MxP was possibly attributed to factors other than the training intervention. One of these probable factors implied by the CT group improvement, was the learning effect that occurred for the subjects performing the stairclimb test. The significant improvements by the MxS and MxP groups may then be due to the subjects lacking the skill or neuro-motor patterns to correctly perform the test at the initial testing sessions. Therefore, it would be then false to state that the improvement in stairclimb power by the MxS and MxP groups was solely attributed to an increase in foot speed or explosive ability. Even though a familiarization session was conducted prior to testing, subjects in the present study still had difficulty performing the high-speed task with proficiency due to the unfamiliar movements required.

Wagner and Kocak (1997) reported increases in the stairclimb test of 17.7 - 19.4% by the treatment groups while the control group only increased 3.2%. The difference in Wagner and Kocak (1997) control results compared to the present study (3.2% vs. 17.06%) may be due to the modification of the Margaria et al. (1966) stairclimb test used by Wagner and Kocak (1997). The modified test was Kalamen's (1968) step test, which consisted of a 6 m approach with 3 step increments instead of a 2 m approach with 2 step increments used in the present study.

Another factor that may have contributed to the CT group improvement in this study was the subject population. The CT group subjects in this study were competitive senior soccer players while the control subjects in the Wagner and Kocak (1997) study received no training or exercise program. The competitive soccer players may have been able to improve their performance in the stairclimb due to their athletic ability.

**Sprints**

The MxS and MxP groups did not statistically improve their sprinting times at distances of 5, 10 and 40 m. Wilson et al. (1993) and Lyttle et al. (1996) used the 30 and 40 m sprints, respectively, to measure sprint performance and neither demonstrated any significant improvements. Consequently, Lyttle et al. (1996) suggested that the incorporation of horizontal plyometric exercises may improve sprints times since the training would be more related to the performance measure. The present study had both training groups performing horizontal bounding and box jumping exercises for the entire plyometric phase of training. The MxP group improved their 5 m sprint time by 7.32% while the MxS group improved by 3.75%. Although the improvement, for the MxP group, was not statistically significant, in a practical sense this small change in the initial acceleration of a sprint may translate into a noticeable improvement in tasks of a short distance. However, since MxS or MxP training did not improve the 10 m or 40 m sprint times, the lack of sensitivity the sprint test has to detect physical adaptations in the subject as a result of training becomes apparent.

**Squat Strength**

In the present study, squat strength displayed the largest improvement over ten weeks of training. From pre to post training, the MxS and MxP group improved by 46.15% and 37.50%, respectively, while the control group improved 11.01%. The difference in strength improvement over time between the MxS and MxP groups was not significant as hypothesized. The improvement observed for squat strength in the CT group may indicate a learning effect with this specific performance measure. However, this learning effect is most likely only present in the CT group since this was the only group having no experience with the squat movement prior to the present study. The near equivalent gains in strength for the MxS and MxP groups were approximately two fold in comparison to the results discovered by Lyttle et al. (1996). The gains in strength by the MxS group have been previously demonstrated in the literature (Atha, 1981; Schmidtbleicher & Haralambie, 1981; Moss et al., 1997; Hoff & Almasbakk, 1995; and Mayhew et al., 1997) as well as for the MxP group (Kaneko et al., 1983; and Lyttle et al., 1996). However, the large degree of improvement in strength demonstrated by both groups is less common. This improvement is remarkable considering all subjects had at least one year of weight training experience in addition to their athletic backgrounds. Moreover, the MxP group's 37.50% increase in the 1 RM squat performance is impressive considering the MxP subjects, who trained at 30% of 1 RM, were unfamiliar with the near maximal loads used for testing. The degree of improvement for the MxP group may have been equivalent to the MxS group (46.15%) if the subjects were more familiar with the testing loads.

Kaneko et al. (1983) discovered that training at 30% of maximum strength produced the greatest all around training effect for maximizing power output and strength improvement in comparison to training at 0, 60 and 100% of maximum strength. Lyttle et al. (1996) attributed the MxP group's significant gains in strength to the large accelerative forces incurred with ballistic jump squats even though the loads were only 30% of 1 RM. Therefore, the key to increasing strength seems to be the amount of force the subject experiences in training rather than the prescribed training load.

One possible method of explaining the effectiveness of jump squats is to consider the potential energy created when performing the ballistic movements. Work can be calculated since the centre of gravity of person performing a squat movement changes throughout the repetition. Although the prescribed load used for training by MxS group was greater than the MxP group, the MxP group had a larger displacement of their centre of gravity due to the ballistic jumping action. In addition, the MxP group performed eight repetitions compared to an average of five for the MxS group. The combined effect of a larger change in the centre of gravity coupled with more repetitions per set may explain the near equivalent gains in strength over the study (See Appendix C for a hypothetical example).

A recent ballistic training study was conducted with elite volleyball players using the Plyometric Power System (PPS) (Newton et al., 1999). The PPS is a modified smith machine in a squat rack equipped with an eccentric brake system that removes 75% of the eccentric load or downward force when performing ballistic movements (Humphries, Newton & Wilson, 1995). Although improvements were noted in vertical jump height, no increases in squat strength were evident over the eight weeks of training. It can then be inferred that the lack of force experienced by the subjects in training, due to the eccentric brake system, may have contributed to lack of strength development. Moreover, Lyttle et al. (1996) also used the PPS machine to perform the ballistic squats, however without the eccentric brake system. The maximum power group had equivalent gains (14.7%) in 1 RM squat strength in comparison to the high resistance-training group (14.8%), which are similar improvement to the results demonstrated in the present study.

The results of the present study agree with Lyttle et al. (1996) and Häkkinen and Komi (1985) that suggest ballistic - type training is effective at increasing strength. This also implies that physiologists and coaches can consider using loaded ballistic movements as a method of developing strength prior to engaging in high velocity exercises.

## Limitations of the Study

The major limitations of this study surround the selection of the CT group. Prior to training, randomization occurred only for the training groups (MxP and MxS). This was primarily due to the lack of volunteers and the low adherence rate to the regulations required of CT group subjects. Therefore, the CT group was not selected from the sample population. A group of six competitive female soccer players volunteered as the control group. Although, the CT group agreed to maintain their physical activity levels throughout the course of the study, they did not conform to all of the inclusion criteria set forth. The CT group was unable to successfully parallel squat their own body weight due the lack of strength and experience with the squat movement. As a result, a predicted 1 RM protocol was used to determine 1 RM squat strength. This inexperience confounded the squat strength results of the study due to a training effect with the testing. In addition, since the CT group only tested at pre and post sessions due to their competitive schedule and personal commitments, this limited the validity of the CT group.

In regards to the measurements of physical performance, the vertical jump test protocol lacked testing specificity to the training methods. Subjects were required not use to use their arms in the vertical jump tests, however, arm involvement was consistently used in the training programs. A jump and reach test with a Vertec would have added a realistic form of testing as previously suggested.

Lastly, a greater number of subjects in the present study would have allowed for a randomized, balanced design with an equal number of subjects in all three groups. In addition, since the training background of the sample population was not uniform, the generalizability of the results to specific populations was limited.

## Strengths of the Study

The training programs designed for this study allowed for an equivalent and unbiased comparison of two distinct training methodologies. Although the total number of repetitions performed for each group was different, the total number of sets were equal. The MxP group performed 8 repetitions per set since this was the average number of repetitions used in the Wilson et al. (1993) and Lyttle et al. (1996) studies as well as in the practical setting. If the repetitions between groups were equated, the MxS group would have most experienced more work over the training period due the larger loads associated with MxS training in comparison to MxP training.

Tan (1999) suggested that equating the overall volume in training programs might actually negate the advantage of using periodized models. Training volume should be treated as a study factor rather than a confounding factor. An experiment that controls for a study factor cannot be expected to show significance between groups (Tan, 1999). This is most evident if the programs are designed to accomplish similar goals, such as strength and power development. Baker et al. (1994) compared three training protocols all equated for volume and intensity. The training programs consisted of a traditional linear periodized model, an undulating periodized model and a training control. Although the programs were of distinctly different training models, no differences were discovered between groups in measures of strength and power. Equating training volume and intensity may appear logical, however as suggested by Tan (1999), this may also take away from the efficacy of the periodized model. The design of this study has permitted definite conclusions to be made about MxP and MxS training.

The training design of this study also had a larger volume and intensity incorporated into the first phase of training in comparison to similar power training studies (Wilson et al., 1993; Lyttle et al., 1996; and Adams et al., 1992). This may explain the improvements subjects made in this study in approximately half the time of the aforementioned studies. The increase in training workload was also accomplished without injury to the subjects. Therefore, large improvements in measures such as squat strength can be accomplished in a relatively short time period if training volume is prescribed similar to the present study.

The periodized training models in this study were split into two distinct training phases. Previous research that have used combined resistance and plyometric methods have not separated the training stimulus into separate phases (Lyttle et al., 1996; Adams, et al., 1992; Häkkinen et al., 1985; Fry et al., 1991; Bauer et al., 1990; and Ford, et al., 1983). Although, improvements were noted with the combination of training methods, research is sparse on combining training in the format used in this study. This form of periodized training is not typically found in the literature and may represent a new area of which to direct the efficacy of periodized training research. The design of this training model has allowed for conclusions to be made regarding the impact of each training stimulus on specific performance measures over the course of the study.

## Final Conclusions

The results of the study suggest that when ballistic training at 30% of 1 RM and maximum strength training at 85-90% of 1 RM are combined with plyometrics, both methods are equally effective at developing power in trained subjects. MxP and MxS training groups improved their stairclimbing power ability. In addition, the ballistic training group (MxP) showed improvement in their static jump and cycle power, however the difference was not statistically greater than the MxS group. The MxP improvement in static jump and cycle power has also been demonstrated by Wilson et al. (1993) and Lyttle et al. (1996) using similar training methods. A trend of improvement in 5 m sprint was also demonstrated by the MxP group. However, the overall speed in the 40 m sprint for the MxS, MxP and CT showed no change over time similar to Wilson et al. (1993) and Lyttle et al. (1996). Ballistic training at 30% of 1 RM has also demonstrated to significantly improve squat strength equivalent to traditional maximum strength training methods. The improvement in strength is consistent with research findings by Lyttle et al. (1996), although to a much greater extent.

Overall, the first hypothesis was demonstrated to not be completely accurate. The MxP periodized training program did not prove to be more effective than MxS periodized training program, despite a slightly greater improvement in power-related tasks. However, the second hypothesis was proven to be correct which stated that both the MxS and MxP groups would increase their strength to a similar extent over time.

## Final Remarks and Future Directions

The most noticeable improvement in this study was the changes in squat strength for the MxS and MxP groups. Both groups displayed a tremendous increase in 1 RM squat surpassing many similar strength and power training studies. In particular, the large increase in strength achieved by the MxP group was remarkable and warrants further investigation. Although some of the gains in strength may be attributed to the sample population and learning effect with a 1 RM parallel squat, this effect was minor due to the training experience and familiarization session the subjects had with the testing protocol. The significant improvement in strength can be attributed primarily to nervous system adaptations due to the short length of the study. These adaptations include an increase in neural firing rates, motor unit recruitment, improved coordination between the agonist and antagonist muscles and decreased inhibition of protective mechanism (golgi tendon organs) (Fleck & Kraemer, 1997). Maximum strength training with high loads has been repeatedly demonstrated in research to be a highly effective method of significantly enhancing strength (Bompa, 1994; Delecluse, 1997; and Atha, 1981). However, the large improvement in strength by the MxP group through ballistic training is less evident in strength training research. The MxP group's increase in strength can be mainly attributed to the large eccentric forces associated with ballistic jump squats causing the neural adaptations previously stated. Nevertheless, due to the difference in training loads between groups (85-90% vs. 30% of 1 RM), the degree and type of neural adaptation may be unique for each group.

Bompa (1996) reported that some physiologists have prescribed depth jumps from heights of 2.50 m for male and 2.10 m for female athletes as a part of their training. The purpose of using extreme heights was meant to "shock" the muscle. The resultant adaptation to this advanced form of plyometrics was an enhanced SSC, as well as, a decreased role of the golgi tendon organs. If the subjects were able to do this training without injury, they would benefit from the ability to produce more force per muscle contraction. The large eccentric force the MxP subjects experienced due to the loaded jump squat may have had a similar training effect on the protective mechanisms and the SSC as with the extreme depth jumps. In addition, the size and velocity of eccentric force associated with ballistic jump squats may have caused the antagonist muscles to become less responsive as the training performance proceeded (Carolan and Cafarelli, 1992; and McComas, 1996). The decreased inhibition of antagonist muscles would allow for a greater stretch rate, and subsequently a more powerful contraction of the agonist muscles leading to improved intermuscular coordination (Zatsiorsky, 1995). These training effects of decreased inhibition and increased intermuscular coordination may have been more pronounced with the MxP group in comparison to the MxS group. The differences in the magnitude of neural adaptation for the MxP group may then account for the large increases in strength despite the light loads. Therefore, heavy loads (85-90% 1 RM) may not always be needed to achieve the neural adaptations required for strength development. Perhaps the key is to stimulate the muscle in a manner that requires high firing rates and motor unit recruitment without protective mechanisms limiting force development.

Future research should attempt to investigate the degree and type of neural adaptation that occurs for different methods of training for strength and power. This information may then assist the physiologist and strength coaches' ability to design programs that will induce positive adaptations in the working muscle. Research on the exact morphological adaptations that occur to the muscle fiber type, protective mechanisms, hormonal profile, neural activation and muscle fiber size are some of the physiological areas that should be explored. In addition, since MxP training is explosive and ballistic, research concerning the impact on bone-joint articulations may also be of interest and importance to physiologists, physicians and coaches.

In regards to training program design, future research should adapt a similar periodized model of distinct training phases in order to evaluate new methods of developing power. Researchers could use either maximal power or maximum strength training to develop strength in the first phase of training. However, in the second phase of the periodized model, different methods of high velocity training can be incorporated to determine their impact on power development.

Research in training program design should also attempt to calculate the amount of work done for maximum strength and ballistic training as previously suggested. This may provide new insights on how to prescribe effective training loads. Training intensity may be then equated between different training methodologies providing for better comparison groups. The work done per exercise could be calculated if the training was performed on a force plate in conjunction with a motion analysis system.

Future research using sprints, as a dependent measure, should consider the lack of sensitivity the test has for detecting change in strength and power training studies as demonstrated by Wilson et al. (1993), Lyttle et al. (1996) and in the present study. Although the sprint test is highly related to physical performance in many sports and activities, sprinting is a difficult measure to improve without specific training. Future strength and power training studies that wish to incorporate more sprint-specific exercises or coaching to enhance sprint performance may face a dilemma at the end of their study. This dilemma being that if an improvement in performance is detected, is the improvement due to the strength training program or the sprint training / coaching?

Lastly, a limitation of past strength and conditioning studies may be the implementation of identical training programs for individuals of different capabilities. Future studies on training effectiveness and performance shoulder consider designing programs specifically for the individual. Strict criteria could be set that account for strength and level of training experience. Subjects could then be grouped into certain categories based upon their capabilities. Training programs may be then more applicable to each individual thereby maximizing positive adaptation.

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# APPENDIX A

## Testing and Training Timeline

| Week | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | x | | | | | x | | | | | x |
| Training | | x | x | x | x | | x | x | x | x | |
| MxS | | MxS Squat | MxS Squat | MxS Squat | MxS Squat | | Plyos & MxS Squat | Plyos & MxS Squat | Plyos & MxS Squat | Plyos & MxS Squat | |
| MxP | | Jump Squat | Jump Squat | Jump Squat | Jump Squat | | Plyos & Jump Squat | Plyos & Jump Squat | Plyos & Jump Squat | Plyos & Jump Squat | |

Plyos = Plyometric Training

### Maximal Power and Plyometric Group (MxP):

- Maximal power jump squats @ 30% 1 RM: Weeks 1-9
- Plyometrics: Weeks 6-9
- Core stability Weeks 1-9

### Maximum Strength and Plyometric Group (MxS):

- Maximum strength squats @ 85-90% 1 RM: Weeks 1-9
- Plyometrics: Weeks 6-9
- Core stability Weeks 1-9

### Control Group (CT):

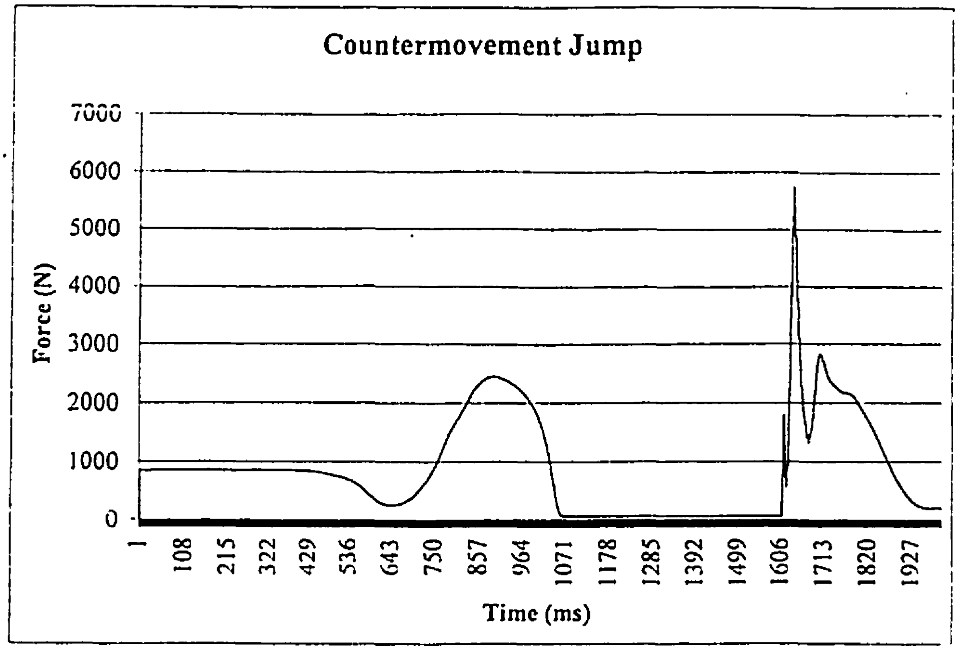
- Core stability Weeks 1-9

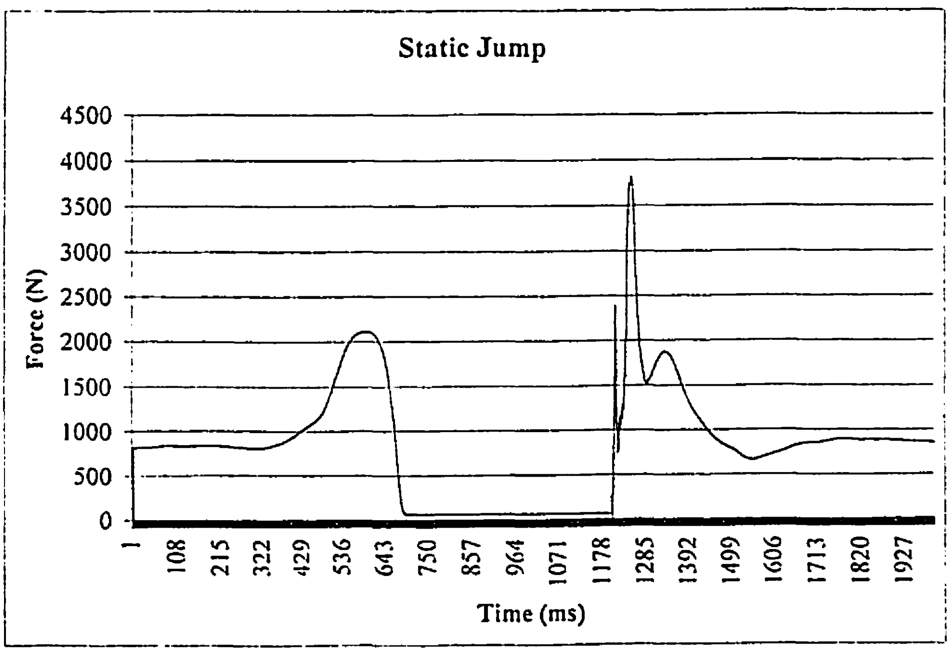
### Performance Tests at Weeks 0, 5, 10:

- Static jump on force platform
- Counter movement jump on force platform
- 7 s anaerobic power cycle ergometer test
- 40 m sprint (times at 5, 10, and 40 m intervals)
- Margaria et al. (1966) stairclimbing test
- 1 RM back squat

## APPENDIX B

### Counter movement jump and static jump force plate graphs



# APPENDIX C

**Hypothetical example of the work done for ballistic and heavy squats.**

**Assumptions:**

| | |
|---|---|
| Mass of individual: | 70kg |
| Acceleration due to gravity | 9.81 $m{\cdot}s^{-1}$ |
| 1 RM load (100%) | 159 kg |
| 85 - 90% 1 RM | 135 - 143 kg |
| 30% 1 RM | 47.7 kg |

**Ballistic Squats (method used in this study)**

| | |
|---|---|
| Repetitions: | 8 |
| Load: | 30% 1 RM (47.7 kg) |
| Total Load (load + subject mass) | 117.7 kg |
| Assumed jump height / rep | 0.20 m |
| Assumed centre of gravity change / squat | 0.50 m |
| Total centre of gravity change with jump | 0.70 m |

Since work = (force * distance) or (mass * acceleration * distance)
Work = 117.7 kg * 9.81 $m{\cdot}s^{-1}$ * 0.70 m = 808 J for one rep
Multiply by 8 to equate a set: 6466 J

*Total work done for ballistic squats per set would be approximately: 6466 J*

**Heavy Squats (method used in this study)**

| | |
|---|---|
| Repetitions: | 4-6 |
| Load: | 85 - 90% 1 RM (135.2 - 143.1 kg) |
| Total Load (load + subject mass) | 205.2 - 213.1 kg |
| Assumed jump height / rep | 0 m |
| Assumed centre of gravity change / squat | 0.50 m |
| Total centre of gravity change with jump | 0.50 m |

Theoretically subjects should be able to perform and 4 reps at 90% of 1 RM and 6 reps at 85% of 1 RM.

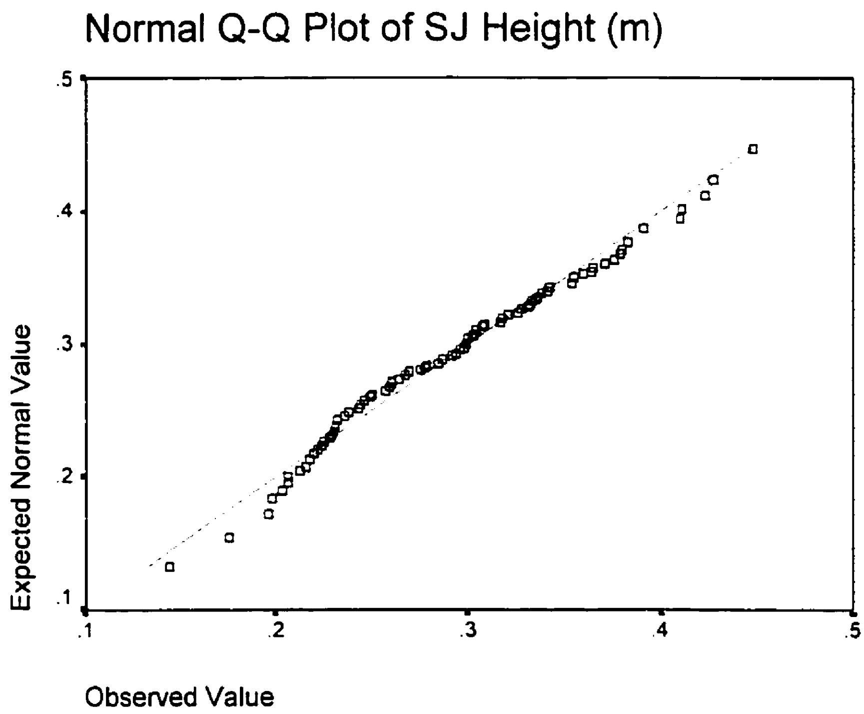
Work = 213.1 kg * 9.81 $m{\cdot}s^{-1}$ * 0.50 m = 1045.3 J for one rep at 90% 1 RM
Multiply by 4 to equate a set: 4181.2 J

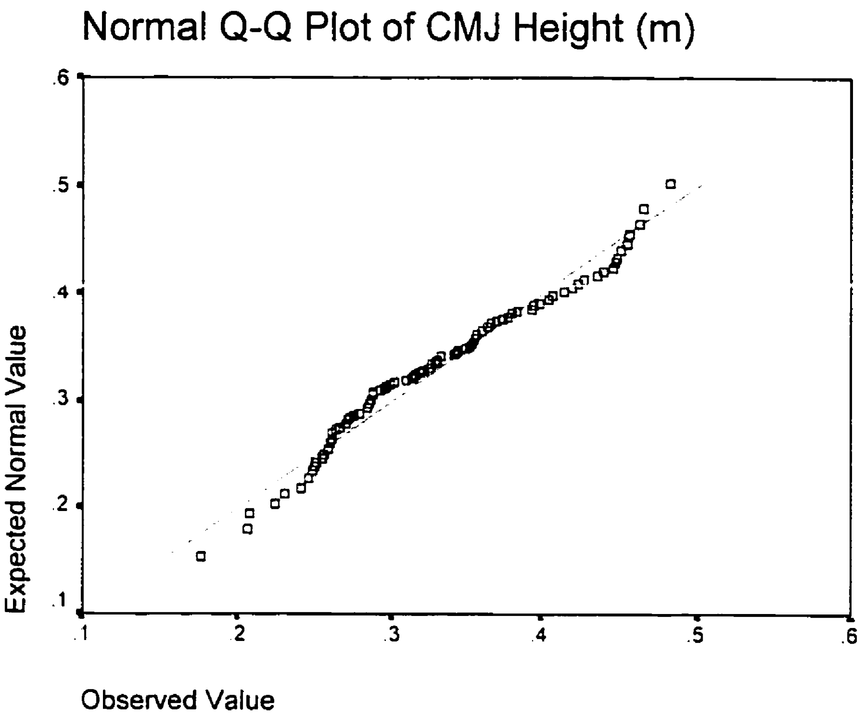
Work = 205.2 kg * 9.81 $m{\cdot}s^{-1}$ * 0.50 m = 1006.5 J for one rep at 85% 1 RM
Multiply by 6 to equate a set: 6039 J

*Total work done for heavy squats per set would be approximately between 4181.2 - 6039J*

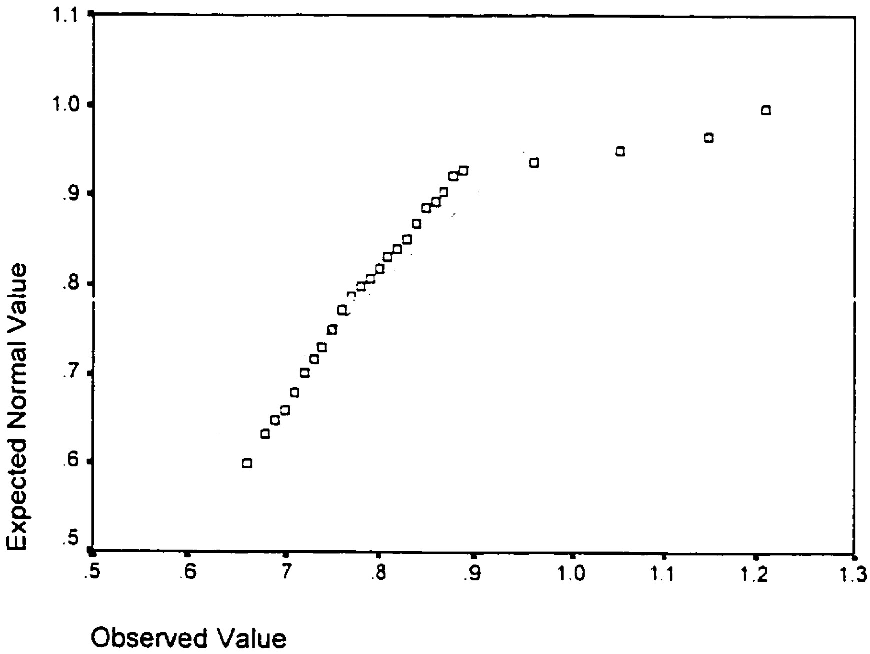
## APPENDIX D

### Normality plots for the dependent variables

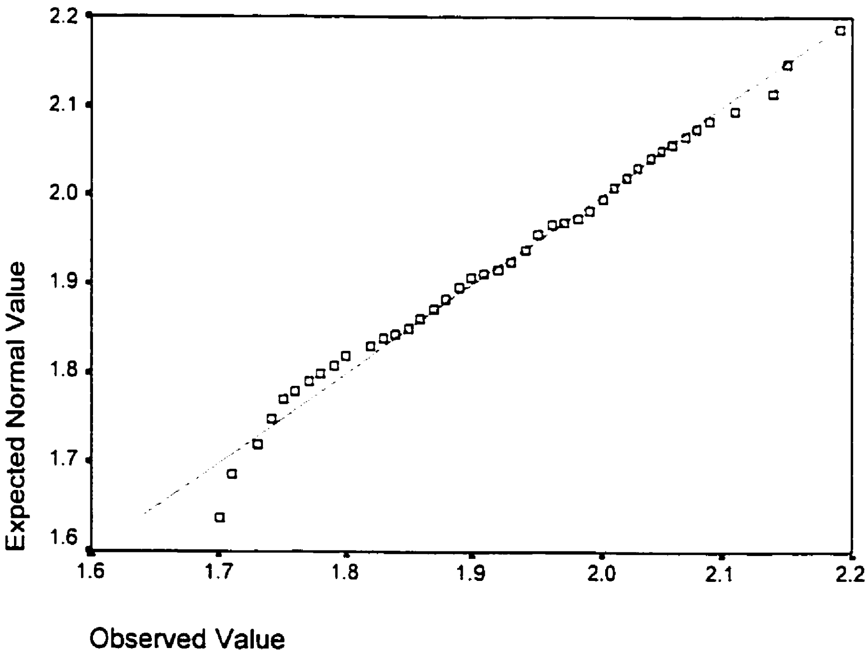


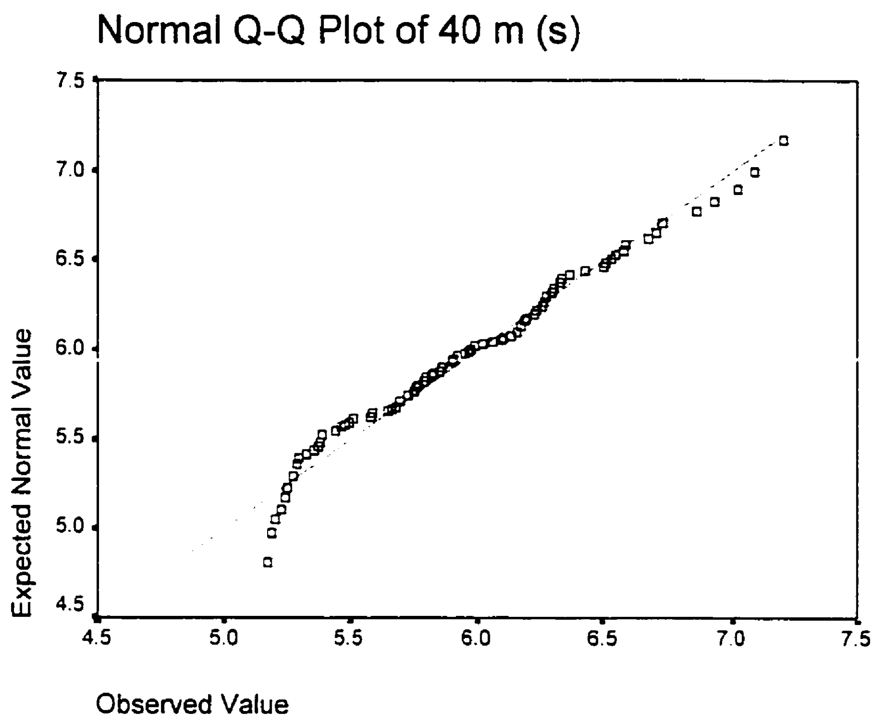

Normal Q-Q Plot of CMJ Height (m)
Expected Normal Value
.6
.5
.4
.3
.2
.1
.1
.2
.3
.4
.5
.6
Observed Value

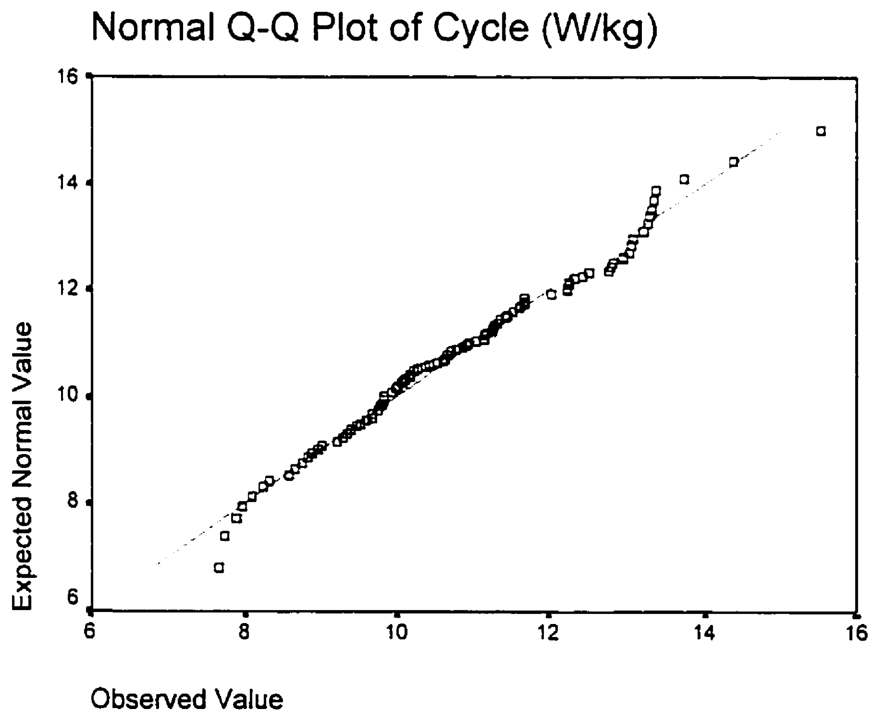
Normal Q-Q Plot of 5 m (s)

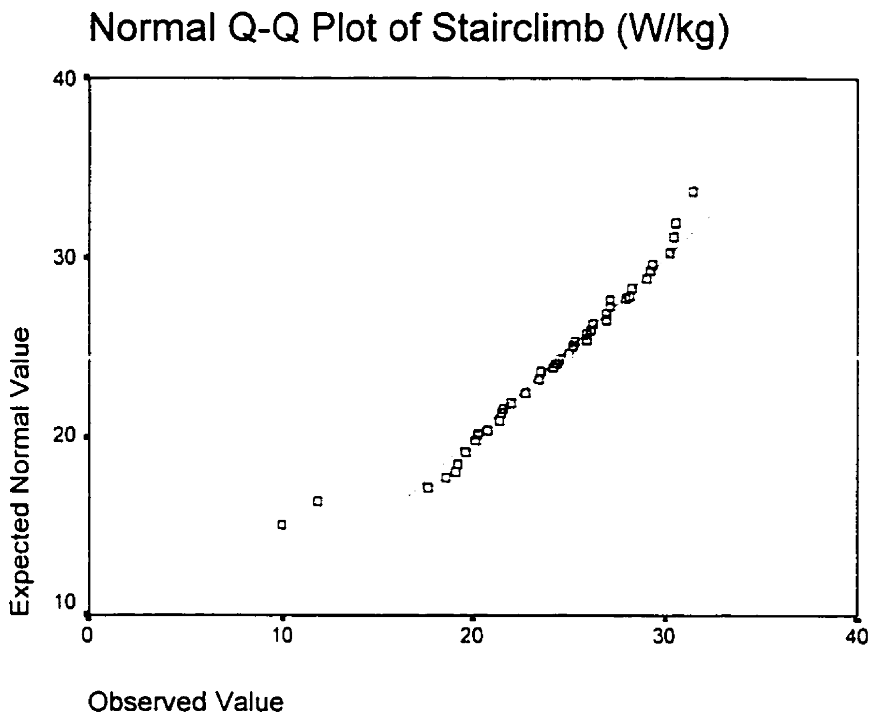


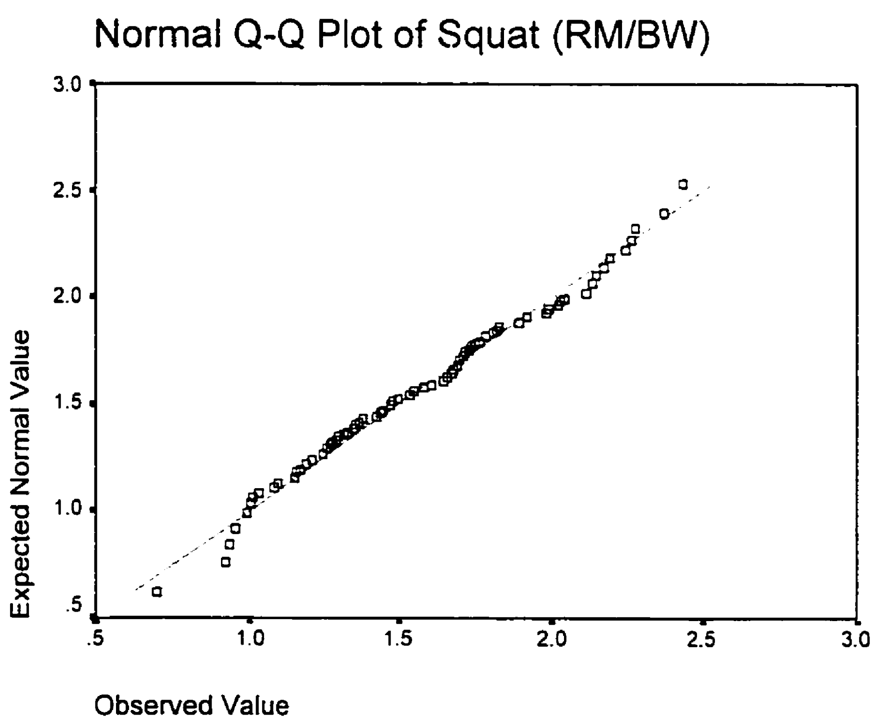

Normal Q-Q Plot of 10 m (s)



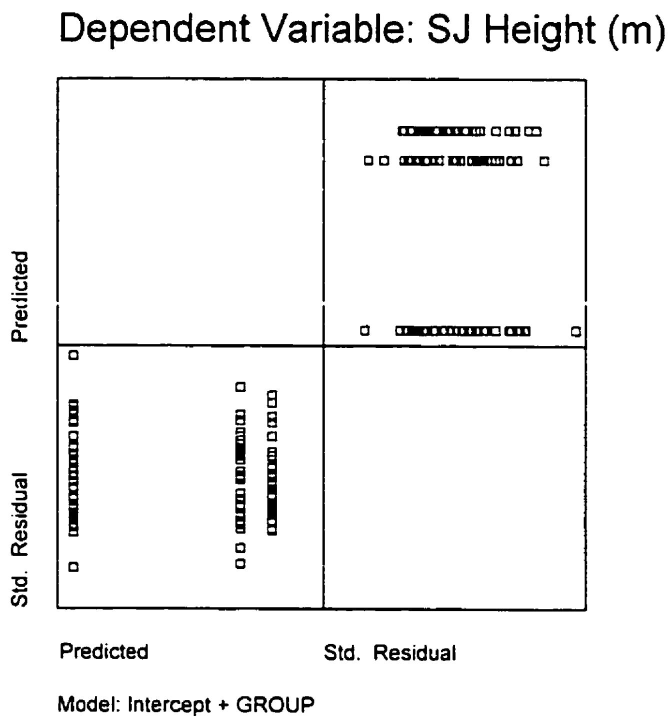

Normal Q-Q Plot of 40 m (s)
7.5
7.0
6.5
6.0
5.5
5.0
4.5
Expected Normal Value
4.5
5.0
5.5
6.0
6.5
7.0
7.5
Observed Value

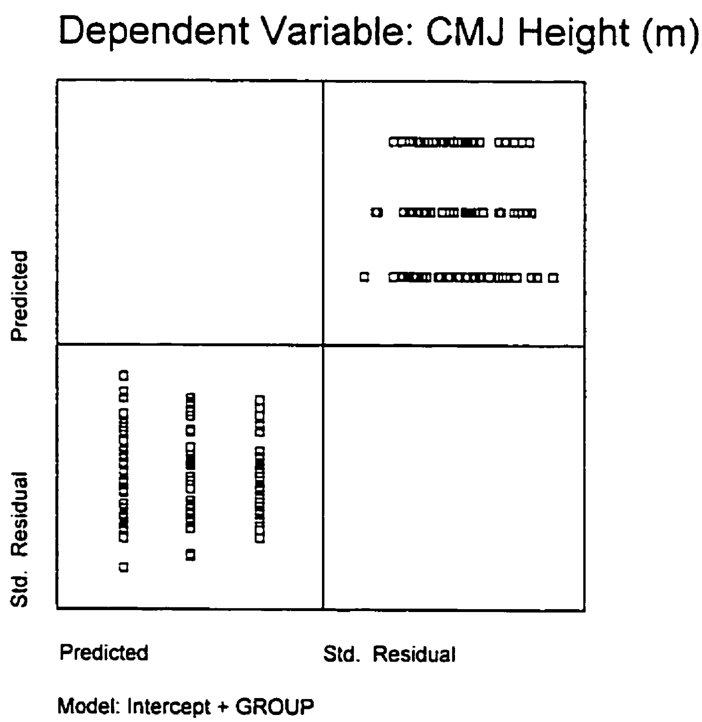

Normal Q-Q Plot of Cycle (W/kg)
16
14
12
10
8
6
Expected Normal Value
6
8
10
12
14
16
Observed Value


Normal Q-Q Plot of Stairclimb (W/kg)
Expected Normal Value
Observed Value
40
30
20
10
0
10
20
30
40

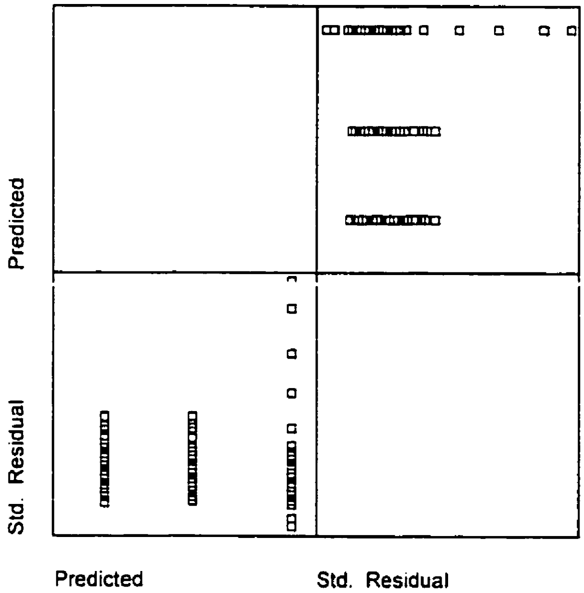

Normal Q-Q Plot of Squat (RM/BW)
Expected Normal Value
Observed Value
3.0
2.5
2.0
1.5
1.0
.5
.5
1.0
1.5
2.0
2.5
3.0

**Plots of Constant Variance for the dependent variables**



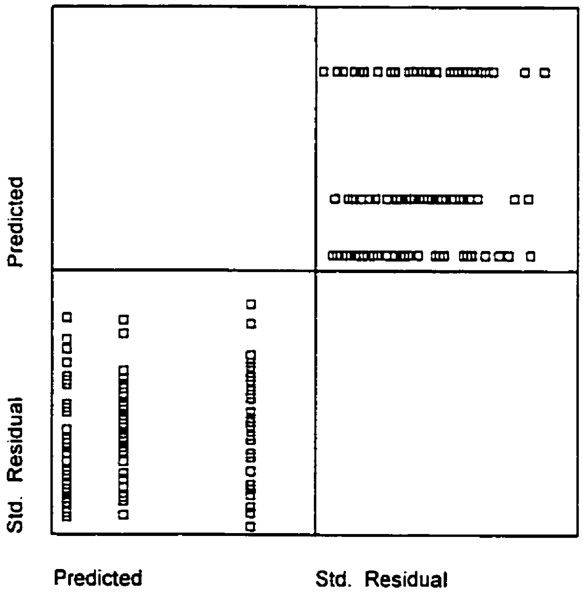



## Dependent Variable: 5 m (s)



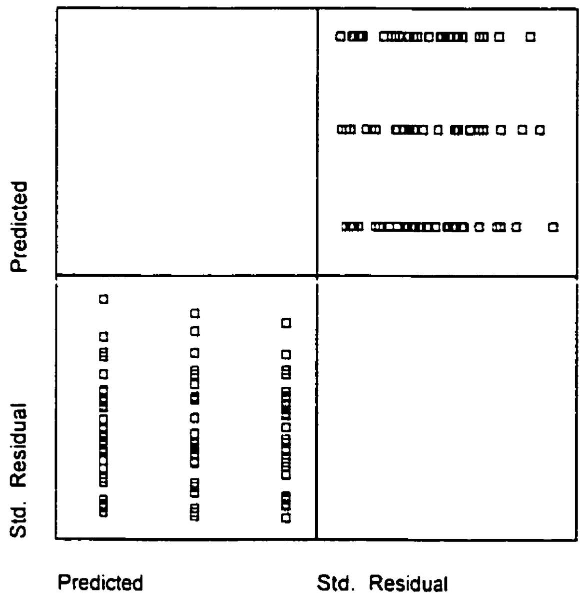

Model: Intercept + GROUP

## Dependent Variable: 10 m (s)



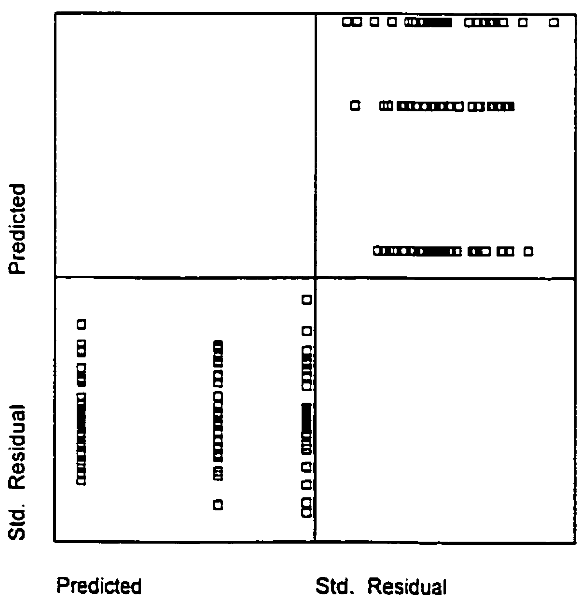

Model: Intercept + GROUP

## Dependent Variable: 40 m (s)



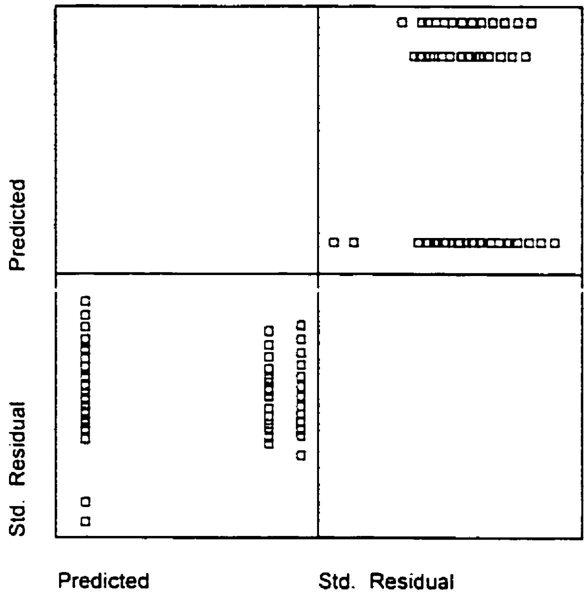

Model: Intercept + GROUP

## Dependent Variable: Cycle (W/kg)



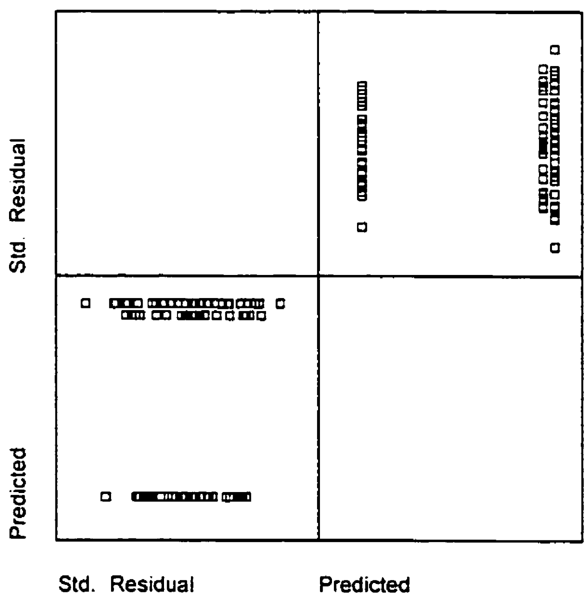

Model: Intercept + GROUP

## Dependent Variable: Stairclimb (W/kg)




Model: Intercept + GROUP

## Dependent Variable: Squat (RM/BW)




Model: Intercept + GROUP

# APPENDIX E

## Ethics Approval Letter

THE UNIVERSITY OF CALGARY
INTER-OFFICE

To: Cory Fagan

**Date:** July 7, 1998

From: Walter Herzog, Chair
Faculty of Kinesiology Ethics Panel

Subject: **Ethics Review**

Please be advised that all ethical concerns have been met for the proposal "The effects of combined maximum strength and plyometric training versus maximum power and plyometric training on the development of lower body power in athletic performance".

P. Bardsley
per Walter Herzog

cc: Dr. P.K. Doyle-Baker

# APPENDIX F

## Consent Form

### POWER TRAINING CONSENT FORM

**The Effects of Combined Maximum Strength and Plyometric Training versus Maximum Power and Plyometric Training on the Development of Lower Body Power in Athletic Performance.**

Investigators: Cory Fagan BPE(Hons)
P. (Tish) K. Doyle-Baker. DrPH. HLEd (supervisor)

This consent form is intended to give the participant a general idea about the research study and what participating in it will involve. It is important to note that participation in this study is entirely voluntary and the participant may withdraw at any time without prejudice. Privacy and confidentiality of individual results will also be enforced throughout the experimental procedure and publication of the study. In addition. if at any time during the study the subject has any questions. concerns or requires additional information. please feel free to ask or call the above investigator at 220-3457 or contact Dr. Walter Herzog. the Associate Dean of Research for the Faculty of Kinesiology at 220-8525. Please take time to carefully read this consent form to be sure you are comfortable and knowledgeable of the required procedures involved in the study as a participant.

The purpose of this study is to determine the effects of combined maximum strength and plyometric training versus maximum power and plyometric training on the development of lower body power in athletic performance.

If you decide to participate as a subject in this study, you will be required to attend training and testing sessions over a 10-week period. Two training groups and one control group are involved in the study. The training groups consist of either Maximum Strength-Plyometrics or Maximal Power-Plyometrics. Participants will be randomly assigned to one of the 2 training groups. You will be required to train 2 days per week for a duration of 8 weeks. The testing sessions will occur at the beginning (week 0), middle (week 5) and at the end (week 10) of the study. Testing will include participation in a 7 s maximal anaerobic power test on a cycle ergometer (Monark bike), a 40 m sprint, static jump, countermovement jump, 1 repetition maximum back squat and a stairclimbing test. All subjects will also participate in a core stability training program for the abdominals and lower back. Training loads will constantly be monitored and adjusted to ensure participants are training at the appropriate intensities. Participants, including the control group, will attend all testing sessions and will be required not to engage in any new forms of lower body training for the duration of the study. Participants will also be required not to engage in any new form of sprint, all-out exercise in the duration of less than 10 s. These limitations will be enforced since additional high intensity training may affect a number of the performance tests in this study. Subjects should also be aware that there is a possibility of incurring muscle strain from performing the maximal exercise tests as well as from the training. Further details about the procedures for participants are given on the accompanying summary information sheet.

All three training groups will be under the supervision of Cory Fagan for the entire training and testing sessions. Dr. P.K. Doyle-Baker will also be supervising the testing sessions. Subjects will be provided with feedback following all of the tests in the experiment. This feedback may provide valuable information to the subject regarding performance, overall fitness, physical well-being and possible changes to a training program. All of the information obtained in this study will be kept in the strictest confidence and the results of the performance on any of the measurements will not be disclosed to anyone other than the subject. In addition, the investigators reserve the right to terminate the involvement of a subject at any time.

Participants will be encouraged to give maximal efforts in the appropriate testing and training sessions which will elevate your heart rate and blood pressure. As a result, temporary dizziness, nausea, and fatigue may occur. However, qualified fitness professionals will be on site to create a safe environment.

Your signature on this form indicates that you have understood to your satisfaction the information regarding your willingness to participate in this study as well as the possible benefits and risks involved and knowing this you agree to participate. However, your signature on this form does not waive your legal rights nor release the investigators or involved institutions from their professional and legal responsibilities.

| | | |
|---|---|---|
| ________________ | ____________ | ____________________ |
| (name of subject) | (date) | (signature of subject) |
| ________________ | ____________ | ____________________ |
| (name of witness) | (date) | (signature of witness) |
| Cory Fagan | ____________ | ____________________ |
| (name of investigator) | (date) | (signature of investigator) |

A copy of this form will be given to you for your personal files.

SUMMARY INFORMATION FOR PARTICIPANTS

**Your voluntary participation in this project will require the following:**

1. 8 weeks of training, 2 days per week for 45-60 min.
2. Responses to a self-administered health questionnaire (PAR-Q)
3. No eating or drinking 2 hours (other than water) before each testing session.
4. Abstaining from vigorous exercise 6 hours prior to each testing session.
5. Fill out an Exercise Log Book to document extra activity/training that occurs outside of this study.

**3 Testing Sessions which will include: Weeks 0, 5, 10**

1. 40 m sprint
2. Static Jump and Countermovement Jump performed on a force platform.
3. 7 s all-out anaerobic power test on a Monark cycle ergometer
4. Maximum back squat
5. Stairclimbing test (time to step between the 8th and 12th stairs)

Methodology:

**Three Groups**

1. Maximum Strength and Plyometrics (random assignment)
2. Maximal Power and Plyometrics (random assignment)
3. Control group (no training – volunteer soccer team)

**1. Maximum Strength and Plyometrics**

**Maximum Strength Squats**

**Weeks 1-4:**

**Load:** 4-6 RM (85-90% of 1 RM)
**Sets:** Progress from 4-7
**Reps:** 4-6

**Weeks 6-9:**

**Load:** 4-6 RM (85-90% of 1 RM)
**Sets:** 2
**Reps:** 4-6

**Power (Plyometrics) Lower Body**

**Weeks 6-9:**

**Load:** Intensity will increase each week

**Core Stability**

**Weeks 1-9:**

Specific exercises will be performed to train the upper and lower abominals, obliques, and lower back.

2. **Maximal Power and Plyometrics**

**Maximum Power Jump Squats**

**Weeks 1-4:**

**Load:** 30% of 1 RM
**Sets:** Progress from 4-7
**Reps:** 8

**Weeks 6-9:**

**Load:** 30% of 1 RM
**Sets:** 2
**Reps:** 8

**Power (Plyometrics) Lower Body**

**Weeks 6-9:**

**Load:** Intensity will increase each week

**Core Stability**

**Weeks 1-9:**

Specific exercises will be performed to train the upper and lower abominals. obliques. and lower back.

3. **Control Group**

**Core Stability**

**Weeks 1-9:**

Specific exercises will be performed to train the upper and lower abominals. obliques. and lower back.

* Participants will be required not to engage in any new form of lower body training that is not a part of this study. Participants, including the control group, will also be required to maintain their present activity levels for the duration of the study.

**Participant Information Sheet**

# Participant Information Sheet

Name: ______________________________ Age:_______ Gender: M or F

Occupation (i.e. student. accountant. teacher): ________________________________________

Training Status (# of yrs. and type of training):

__________________________________________________________________

__________________________________________________________________

Are you currently training? Y or N (please circle) If yes, what type of training?

__________________________________________________________________

Present days / week of training (number and duration):

_______________________

Athlete? Y or N (please circle) If yes, what sport/activity:

_______________

Preferred training days for this study: Mon-Thurs or Tues-Fri (please circle)

Preferred training times for this study:
Mornings __________AM and/or Evenings _________ PM

## Medical History:

Physician: ______________________ Phone:___________________

1. How would you describe your present state of health?
   Excellent Good Fair Poor (please circle)

2. Have you suffered any major injuries? If yes, how long ago? _________
   Nature of Injury: ____________________________________________
   Present Limitations: __________________________________________

3. Within the last two years, have you been treated by a physician or another health professional for a medical illness or condition? (i.e. asthma, high blood pressure, heart problems, stroke, diabetes, thyroid problems, phlebitis, etc.)

Nature of illness? ____________________
Present limitations? ____________________

4. Have you used any prescription drugs, supplementation products (i.e. vitamins, creatine monohydrate) in the last 6 months?
Type of drug or supplement? ____________________
Dosage of drug / supplement? ____________________
Reason for taking medication / supplement? ____________________

5. Have you undergone any surgery? ____________________
How long ago? ____________________
Nature of the surgery? ____________________
Present limitations? ____________________

6. Do you have back problems? ____________________
Has the problem been diagnosed by a physician? ____________________
Present limitations? ____________________

7. Do have any other injury or ailment that may affect your ability to do high resistance back squats and/or jumping exercises? ____________________

____________________

8. Do you have any other medical condition not asked in this questionnaire that may be relevant to training in this study? ____________________

____________________

Date: ____/ 06 /1998

Signature: ____________________

Phone number(s) where you can be contacted: ____________________

## Physical Activity Readiness Questionnaire

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 1994)

# PAR - Q & YOU

**(A Questionnaire for People Aged 15 to 69)**

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

| YES | NO | | |
|---|---|---|---|
| ☐ | ☐ | 1. | Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor? |
| ☐ | ☐ | 2. | Do you feel pain in your chest when you do physical activity? |
| ☐ | ☐ | 3. | In the past month, have you had chest pain when you were not doing physical activity? |
| ☐ | ☐ | 4. | Do you lose your balance because of dizziness or do you ever lose consciousness? |
| ☐ | ☐ | 5. | Do you have a bone or joint problem that could be made worse by a change in your physical activity? |
| ☐ | ☐ | 6. | Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition? |
| ☐ | ☐ | 7. | Do you know of <u>any other reason</u> why you should not do physical activity? |

**If you answered**

### YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

### NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

**DELAY BECOMING MUCH MORE ACTIVE:**

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

**Please note:** If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

**You are encouraged to copy the PAR-Q but only if you use the entire form**

*NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.*

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

NAME ____________________

SIGNATURE ____________________ DATE ____________________

SIGNATURE OF PARENT ____________________ WITNESS ____________________
or GUARDIAN (for participants under the age of majority)

continued on other side...



*Supported by:* Health Canada Santé Canada