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The purpose of this investigation was to determine the effectiveness of a 6-week strength training program consisting of squat and plyometric exercises on vertical power jump performance, static and dynamic muscular strength, and muscular power production in college age adults. Fifteen male and two female college students in an advanced weight training class at the Oregon State University served as subjects for the study. Nine subjects trained only with squat exercises whereas eight subjects trained with combined squat and plyometric exercises. All subjects trained twice a week for six weeks. A pre-test and post-test randomized groups design was utilized in this study. The statistical analysis was conducted using a paired *t*-test, and a repeated measures analysis of variance (ANOVA). A .05 level of significance was selected for rejection of the null hypothesis ($p < .05$). The results of the training programs indicated a significant mean increase ($p < .05$) from the pre-test to post-test for the vertical power jump within the combined squat and plyometric training. Static strength significantly decreased (p <

.05) from the pre-test level to the post-test level within the squat training program. Hamstring strength and hamstring power were significantly different ($p < .05$) within both training programs when pre-test and post-test mean scores were compared. However, no differences existed between the gains achieved by the two training programs.

The results of this study will assist physical educators and coaches in designing more effective training programs both at the high school and college level.

The Effects of Six Weeks of Squat and Plyometric Training on Power Production

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CHAPTER 1

INTRODUCTION

Strength and power have importance in many types of sports. They are the key factors involved in weight lifting, throwing, jumping, and sprinting events. A high level of strength and power is usually associated with a greater ability to accelerate the body mass or propel external objects (MacDougall, Wenger & Green, 1982).

East German research indicates that in track and field, throwing events require optimal relationships between strength and speed. Throwers need to concentrate on developing explosive-reactive-ballistic movements. This type of movement is based on the principle of prestretching the muscle and using stored energy for throwing (O'Shea, 1985b).

Strength and speed must be considered the cornerstones of almost all athletic events. An operational definition of each is important here in order to clarify the problem to be investigated by this study.

Functionally, muscular strength is the force that a muscle, or group of muscles, can exert against a resistance in one maximal voluntary contraction (DeLateur, 1984; Heusner, 1981). Athletic strength is applied through a full range of multiple joint movements and speed movement. Since muscle fibers produce torque or dynamic contraction under various conditions of sport movements, one of the most important exercises for development of dynamic strength is the parallel squat. The muscles involved in executing the squat undergo an eccentric and concentric contraction. Combined eccentric and concentric contractions produce a greater force than each type of contraction alone. The squat also has a positive influence on overall neuromuscular efficiency (O'Shea, 1985b). This training, which depends upon a powerful thrust from the hips and thighs, can be transferred to other biomechanically similar movements through specialized training such as plyometrics and squat.

Speed is related to distance over time, and the rate at which an object moves (Luttgens & Well, 1982). Speed is based on both an internal and external component. Internal speed refers to complex neuromuscular movement. Internal speed is the rate at which the nerve impulses are transmitted through the nervous system. External speed refers to the speed or velocity of limb movement (O'Shea, 1985b).

One of the primary objectives of athletic type strength and speed training is to optimize body power production. Power, strength, and speed are interrelated. Power is the product of strength and speed as illustrated in the following equation (Bauer, 1986; Johnson & Nelson, 1986; Poprawski, 1987; Westcott, 1987):

$$\text{Power} = \text{Strength} \times \text{Speed}$$

$$(\text{Force}) \times (\text{Velocity})$$

or

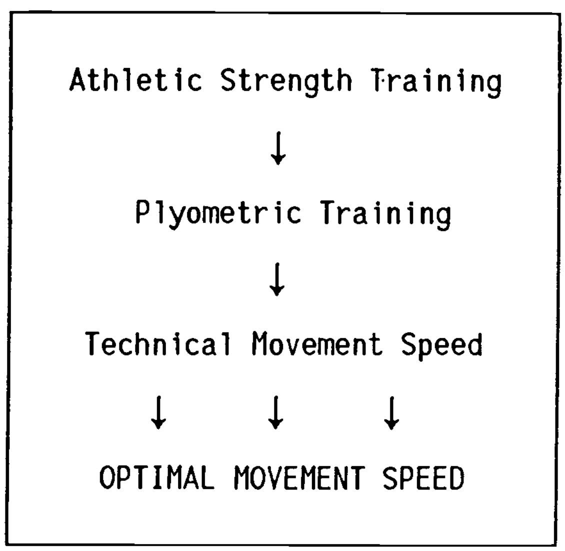
$$\text{Power} = \text{Body weight (Force)} \times \text{distance/time}$$

When there is a gain in strength and/or speed, there will be a corresponding increase in power.

Since speed is the result of a complex neuromuscular phenomenon, it is difficult for some individuals to attain speed in athletic performances despite repetition of a sports skill. However, speed is enhanced through the development of more efficient nerve pathways over time. Speed can be increased through training. It has been demonstrated that increased speed in muscle contraction will increase power (Westcott, 1987). The ability to use strength at fast limb velocities to produce maximal power output has limited influence on the interplay of strength, speed, and technique. O'Shea (1985b) has stated that the key to athletic strength development is high intensity, full-range, multiple joint weightlifting movement involving heavy resistance ($85\%^{+}$ of a 1-RM). Improvement in strength, however, must be accompanied by the application of good technique (see Figure 1.1). For example, one of the primary factors for improving movement speed in field events is long-term technique work utilizing lighter or actual throwing implements such as shot, discus, or hammer.

Figure 1.1

Relationship between strength-speed and technique.



Strength is the ability of the neuromuscular system to produce force that initiates and sustains movement and is enhanced through free weight training and plyometric training. Both training programs may be considered the link between strength and speed (Howard, Ritchie, Gater, Gater & Enoka, 1985; Westcott, 1987).

In the past ten years, European and Russian coaches in track and field have realized the importance of maximizing power in jumping, throwing, and running by linking the strength and speed of movement. The relationship produces the "explosive-reactive power" known as "plyometrics." Yuri Verkhoshanski, a Russian, contributed the idea of plyometric training and experimented with "depth jumping" and the "shock" method as plyometric techniques for increasing neuromuscular development, explosive-reactive power, and dynamic strength (Chu, 1983).

Plyometrics refers to exercise characterized by powerful muscular contraction in response to the eccentric-concentric activity which loads (stretches) the elastic and contractile components of muscles (Lundin, 1985). The combination of both eccentric and concentric training is thought to enhance muscular strength and power to a greater degree than concentric alone (O'Bryant, 1985). Plyometrics is necessary for the development of the neuromuscular reflexes, stretch reflexes, explosive power, and ballistic movements (Chu, 1983).

In athletic type strength training, the squat is the foundation exercise critical to basic strength development. Squatting involves the use of many major muscles of the "Power Zone" (thighs, hips, and lower back). These are the powerful explosive muscles used in running, jumping, throwing, and nearly every other type of athletic movement. The squat optimizes not only strength but also speed, explosive power, and muscular endurance (Kroll in Coach Roundtable, 1984). The strength acquired through squatting may be utilized to a greater degree in athletics through plyometric training.

Statement of the Problem

Today in athletic strength training, squats and plyometrics are recommended to maximize jumping, throwing, and running speed in such sports as basketball, volleyball, and track and field. Sport physiologists in general believe that squats and plyometric training can maximize speed, which in return will increase power production. At the present time however, there is no published research to support this training theory.

Purpose of the Study

The purpose of this study was to determine the effects of a 6-week strength training program of squats and plyometrics on power production.

Hypotheses

Hypothesis I: No significant increase will be found in vertical power jump performance, in static strength, in dynamic strength, and in power production between groups subjected to six weeks of squat training, and six weeks of combined squat and plyometric training.

Hypothesis II: No significant increase will be found within groups between the pre-test and post-test mean scores for strength and power.

Basic Assumptions

The basic underlying assumptions of this study were:

1. Leg and hip power was required by both the squat and plyometric exercises.

2. The subjects performed maximally in their six weeks training program and during the testing periods.

Delimitations

Delimitating factors with respect to the scope of this study were that:

1. Subjects were collegiate advanced weight training students at Oregon State University during the winter term of 1988.

2. Observations were focused on the increase in strength and power production.

3. Two experimental groups were utilized in the study.

Research Limitations

The limitations were that:

1. Leg power was determined by measuring the height of the jump and the time required to complete the jump. The output generated by the Cybex II dynamometer was also used to determine the muscular power of the quadriceps and hamstrings.

2. Leg strength was measured only by the cable tensiometer and the Cybex II dynamometer.

3. The subjects were 15 male and two female collegiate advanced weight training students from one class at Oregon State University.

4. All subjects trained only two days a week for six weeks. Each workout session lasted 50 minutes.

5. Control of physical activities outside squat and plyometrics was not possible.

6. Verbal motivation of the subjects to perform at maximum capabilities could not be controlled completely.

Operational Definitions

For the purpose of this study, the following definitions are provided.

Plyometrics--Exercises aimed at linking absolute strength and speed of movement to produce an "explosive-reactive" type of movement often referred to as "power". The exercises involve powerful muscular contraction in response to rapid, dynamic loading (stretching) of the muscles involved (Chu, 1983).

Plyometric training--A 2-type movement: 1) Depth jumps are an exercise utilizing the body weight of the athlete and the force of gravity to exert force against the ground. These exercises are done by stepping off a box from a height of 0.71 meters, followed by an immediate rebound jump vertically upwards (Chu & Plummer, 1984; McFarlane, 1985); and 2) box jumps are performed by jumping up to a height of 0.71 meters from a double leg take-off (McFarlane, 1985).

Squat--Parallel squat lift where, with the weight bar positioned at the base of the neck, the lifter lowers down to a squat position. During the squat lift the top of the thigh is parallel to the ground; and then, with an explosive upward movement, returns to an erect position (starting position).

Periodization concept--A sophisticated method of athletic training that involves scheduled and logical organization and conditioning over a prolonged time. Training encompasses the major physiological concept of specificity, overload and variety. The macro- (multi-year), meso- (yearly), and micro- (weekly) training cycles were developed to meet this need. The micro-periodization consisted of a 6-week training program of squat and combined squat and plyometrics (Auferoth, 1986; Stone, O'Bryant, Garhammer, McMillan & Rozenek, 1982; Yessis, 1982).

Cybex II dynamometer--An electromechanical instrument which measures static and dynamic strength, muscular endurance, and power. The Cybex II dynamometer consists of a small DC servomotor employing tachometer feedback control. A particular velocity has been set; the motor resists acceleration that would be caused by applied torques. The applied torques are measured in two opposite directions (clockwise and counterclockwise). The Cybex recording displays torque and angular velocity which can be used to calculate power. The calibration of torque and velocity can be determined from the Cybex publication manual (MacDougall et al., 1982).

Vertical power jump--A method used to assess "explosive power" in the leg when jumping vertically upward. This test designed to obtain a subject's power output, has reliability, validity, and objectivity (Johnson & Nelson, 1986).

Cable tensiometer--An instrument used to indicate static strength in terms of tension which is converted directly into pounds from a calibration chart. This number is then transformed to Newtons in SI units (American College of Sports Medicine, 1971). The reliability of the cable tensiometer is quite high; objective coefficients for practically all tests were .90. The equipment required for the various tests with the cable tensiometer includes a strap with D ring, a pair of cables with adjusters, a goniometer to establish correct joint angles, and a specially constructed table for various exercise positions (Clarke & Munroe, 1970; Johnson & Nelson, 1986).

Automatic performance analyzer--An electrical timing device which measures reaction time, movement time, contact time, and time in the air on a jump. It contains two recording channels so that split times can be obtained. A switch mat that measures the time between take off and landing is used for vertical power jumps. The timer starts when pressure is taken off the mat. The timer stops when pressure is returned to the mat. The basic unit is built with a solid state digital read out timer calibrated in milliseconds and accurate to 1 millisecond (Instruction Book: Automatic Performance Analyzer, 1985).

Strength--The peak force or torque developed during a maximum voluntary contraction (MVC). The International System of Units (SI) for force and torque are the Newton (N) and Newton·meter (N·m), respectively (MacDougall et al., 1982).

Static strength--The maximum effective force that can be applied only once to a fixed object by a subject in a standardized immobile position. The object cannot be moved through a range of motion and the force is measured by a leg lift tensiometer (Kirkendall, Gruber & Johnson, 1987).

Dynamic strength--The maximum load that can be moved once throughout a specific range of motion. This type of dynamic strength is known as isokinetic strength. This is the maximum torque which can be exerted against a preset rate-limiting device as measured by the Cybex II dynamometer (DeLateur, 1984; Kirkendall, et al., 1987).

Power--Athletic power can be considered as the output from a series of muscular contractions producing force over a particular distance in a period of time or at a specific limb velocity or speed. Therefore power is measured through muscular strength x limb velocity (Bauer, 1986). Power is also estimated as the product of body weight acting through the vertical distance in a given recorded time (Johnson & Nelson, 1986; Poprawski, 1987). The SI unit for power in the vertical power jump is kilogram·meter per second (kg·m/sec) and for the Cybex II dynamometer is the watt (W).

Repetition--The number of times a dynamic or static contraction is repeated in a given exercise set. One repetition maximum (1-RM) is the maximum load a muscle is able to contract for one repetition. Thus, 2-RM is the maximum load a muscle can contract against for two repetitions, and so forth.

Set--One series of repetitions without a rest for a given exercise. A set may be repeated any predetermined number of times.

Relative strength--An expression of the amount of force or torque produced by individuals (as measured by the cable tensiometer and the Cybex II dynamometer) divided by body weight. This term is the strength-to-body-weight ratio.

Hamstring/Quadricep strength ratio--A ratio of the amount of torque produced by an individual's hamstrings divided by the torque produced by the quadriceps.

CHAPTER 2

LITERATURE REVIEW

The literature pertaining to squat and plyometric training programs is concerned with relationships of strength, speed, and power, as well as the operation of neuromuscular mechanisms, and response to training. Literature has focused on muscular physiology, neuromuscular functions in strength and power, and neuromuscular adaptation in strength and power training. Published findings have also dealt with strength development in squat and plyometric training, power development in squat and ploymetric training, and combined squat and plyometric training.

Muscular Physiology

Muscular physiology concerns the study of function in muscle systems. Physiology attempts to explain the physical and chemical factors that are responsible for the origin and development of muscle. There is a relationship between muscular physiology and specificity of training. Training has a very important role in development of particular muscle characteristics (McCafferty & Horvath, 1977). Strength and power training are linked with muscle fiber type, the muscular sensory system, speed of contraction, and metabolic characteristics of the muscle.

Muscular Sensory System

Movement or motor control, is regulated by the central nervous system (CNS) utilizing sensory feedback available from proprioceptors. The proprioceptors that are of prime concern in understanding the neurophysiology of squat and plyometrics, are the muscle receptors which include the Golgi tendon organ (GTO) and muscle spindle (MS). The proprioceptive reflexes in motor skills are generally controlled by the MS and GTO, their effects being facilitation, reinforcement, or inhibition of muscle contraction (Lundin, 1985).

Muscle Spindles

The muscle spindles are widely spread within muscle tissue. They consist of intrafusal muscle and extrafusal fibers. The intrafusal fibers do not contribute to the force of contraction, but the extrafusal fibers are responsible for the development of external tension.

When the external stretch is applied, a distension occurs in both fibers. Lundin (1985) found that stretching the intrafusal fibers evokes sensory discharge to the spinal cord which, in turn, causes a motor response as the stretched muscle contracts. There is a corresponding inhibition of the antagonist muscle. It is called the myotatic or stretch reflex. It is responsible for the control of movement and posture maintenance. The advantage of the stretch reflex may be in spindle activity because the muscle must be forcibly stretched. The velocity of the stretch causes a rapid rise in the firing frequency of the MS. The resulting increase in the MS activity makes maximum use of storage and releases kinetic energy in the muscle itself (Astrand & Rodahld, 1977; O'Connell & Gardner, 1972).

Golgi Tendon Organ

The Golgi tendon organ has an inhibitory effect upon muscles. The inhibitory reflex of the Golgi tendon organ is a protective measure to monitor and prevent dangerously high tension within the muscle (Schmidt, 1982). Since the Golgi tendon organ may respond to high stretch or high tension, the inhibitory effect may be overcome and injury is possible.

Howard et al. (1985) mentioned that inhibition removal can result in increased motoneurons activation and greater force output. In strength training, neuromuscular inhibition may play a role via the following three mechanisms: (a) bilateral inhibition; (b) tendon organ and other force-sensitive inhibition; and (c) precontraction of antagonists. Bilateral inhibition has implications for strength and power output.

Elastic Properties of Muscle

There are two types of elastic components present in muscles: the parallel-elastic component, and the series-elastic component (Edgerton, Roy, Gregor, & Rugg, 1986).

The storage and release of elastic energy has been investigated extensively by Cavagna and his associates (1968, 1971, 1977). They found that the positive work (concentric or muscle shortenings) in level running was higher than energy expenditure. It was suggested that positive work is derived mainly from the recoil of elastic elements. The greater muscle force during lengthening (eccentric) contractions is a greater stretch and consequently results in greater stored energy in the series-elastic component. As the muscle contracts concentrically, kinetic energy can be recovered and utilized to contribute to the positive work (Cavagna & Kaneko, 1977).

The ability to utilize stored kinetic energy is based on time, the stretch magnitude, and the stretch velocity. If there is no time delay between the eccentric and concentric contractions, some of the stored kinetic energy will be dissipated (Cavagna & Kaneko, 1977). The greater the magnitude of the lengthening contraction, the fewer the number of crossbridges that will remain attached following the stretch. Less kinetic energy will be stored (Edman, Elzinga & Noble, 1978). The greater the velocity of stretch during the eccentric contraction, the greater the storage of kinetic energy (Rack & Westbury, 1974).

Norman and Komi (1979) and Komi (1984) noted that the combination of eccentric and concentric contractions stemmed from a natural type of muscle function called the "stretch-shortening cycle." This process permits the final action (concentric contraction) to occur with greater force or power output than a movement initiated by concentric contraction alone.

The ability to change quickly from lengthening to shortening contractions is the key to utilizing the elastic component. Bosco and Komi (1979) proved that power values were much higher with jumps involving minimal knee flexion compared to jumps with increased knee flexion.

Motor Units

The motor units consist of a motoneuron and the number of muscle fibers they innervate. There are two major types of muscle fibers which differ histochemically, biochemically, and metabolically. In general, the two fiber types are identified as slow twitch (ST or SO; or type I fibers), and fast twitch (FT or FG; type II fibers).

The ST fibers have a high oxidative and low glycolytic capacity. They are recruited for low intensity and for long-term activity. The FT fibers have a low oxidative, high glycolytic capacity, and are recruited for high intensity, short duration anaerobic type activities (Palmierei, 1983; Howard et al., 1985).

The physiological differences between the fiber types are determined by the fundamental differences found in the ultrastructural and metabolic properties. In fast fibers, calcium uptake by the sarcoplasmic reticulum, the actomyosin cycling rate, ATP hydrolysis, and anaerobic regeneration of ATP are all uniformly high. The FT muscle is used primarily for high intensity anaerobic work and as a result, produces large amounts of lactate. In contrast, ST fibers depend on aerobic oxidation of both fats and carbohydrates to produce high energy production. The actomyosin cycling rate, ATPase activity, and calcium uptake by the sarcoplasmic reticulum are lower than the FT fibers (Green, 1986).

Muscle fiber types are highly specific and are determined largely on the basis of histochemical criteria. The FT fibers consist of two types: 1) fast oxidative glycolytic (FOG) or type IIA and 2) fast glycolytic (FG) or type IIB.

The FOG or type IIA is an intermediate fiber and is more fatigue resistant than type IIB. The FG or type IIB has greater anaerobic capacity, a higher content of enzymes, larger mitochondria, higher myoglobin content, and has a higher tension output (Palmierei, 1983; Howard et al., 1985).

In many muscles of the human, the expression of the maximal force output would be expected to involve maximal or near maximal recruitment of both ST and FT motoneuron pools (Belanger & McComas, 1981). In general, during very rapid voluntary contractions there is orderly recruitment of motor units according to the size principle (Green, 1986). The smaller ST fibers are always recruited first, the FOG fibers next and the FG fibers last. In a mixed muscle containing both ST and FT fibers, the involvement of ST fibers is obligatory.

Extreme endurance training may cause fiber-type conversion (Howard et al., 1985; Pette, 1984). Strength training has not been shown to induce conversion of fiber types based on natural schemes. Westcott (1987) mentioned that there is no evidence to show that ST fibers may be turned into FT fibers or vice versa since this would require changing the entire nerve innervation network.

In view of the difference between the ST and FT fibers, the athletes' performance in activities requiring rapid development of force and high power outputs tend to have a predominance of FT fibers (Gollnick, Armstrong, Sanbert, Piehl, & Saltin, 1972; Costill, Daniels, Evants, Fink, Krahenbuhl, & Saltin, 1976). O'Bryant (1985) stated that in general endurance athletes have higher slow twitch percentages while strength-power athletes have higher fast twitch percentages. Some studies showed a postive relationship with the percentage of FT fibers and power output. The FT fibers, especially type IIB fibers need to be developed to facilitate the great production of speed, strength, and power.

Neuromuscular Functions and Adaptations

Through the application of scientific athletic training programs many physiological systems respond to specific exercises.

Training for strength or power events initiate changes in neuromuscular functions and subsequently cause neuromuscular adaptations (O'Shea, 1979; Stone, 1982; Yessis, 1981).

Neuromuscular Functions in Strength and Power Training

Edgerton et al. (1986) stated that a muscle's physiological cross-sectional area, muscle fiber length, and muscle mass are the primary morphological determinants of maximal force, velocity, and power, respectively. Guyton (1986) pointed out that muscle fibers produce 3.5 kilograms of force over a 1 cm^2 cross-sectional area.

Moritani (1978) observed the changes in the neural aspects of muscle strength by quantifying muscle activation. Levels were measured by electromyographic (EMG) instrumentation over an 8-week training period. It was found that early changes in strength were largely due to neurofactors. The results suggested that increased levels of muscle activation may be induced by greater facilitation and greater disinhibition occurring at various levels of response within neural system pathways.

Electromyographic (EMG) studies have attempted to monitor the effect of strength training on motor units discharge during voluntary contractions. Research showed that long term training studies have increased motor unit synchronization. Moreover, cross-sectional studies have shown motor unit synchronization to be enhanced in weight lifters and in others who regularly perform brief, maximal contractions (Milner-Brown, Stein, & Lee, 1975). Synchronization of motor unit firing is essential to power production. Results have shown that decreases in both the integrated EMG

(Hakkinen & Komi, 1983) and motor unit synchronization (Milner-Brown et al., 1975) follow detraining and periods of extreme inactivity.

Stone (1982) listed the following determinants as having great strength and power production.

1. The number of motor units involved determines the strength of muscle contraction. Greater force is produced with increasing fast twitch fiber activation.

2. The frequency (rate) of motor unit firing will cause increases in maximum force with increases in firing rate.

3. When there are a large number of motor units which contract simultaneously, motor unit synchronization will produce very forceful muscular contractions.

4. The pattern of motor units and whole muscle contractions will lead to more efficient performance.

5. The muscle fiber type will play an important role in producing a greater force output in fast twitch motor units than slow twitch motor units.

6. The degree of muscle hypertrophy can be determined from the forceful tension output within a large cross-section of muscle.

<u>Neuromuscular Adaptation in Strength and Power Training</u>

Strength and power training may cause changes in the nervous system. These changes result in better muscle group coordination, and greater force output.

Strength development is due to nerve-muscle adaptation; only the nervous system can stimulate the muscle in a particular manner for a specific response. When beginning to train, the nervous system is usually at a high level of excitation and has a high energy response enabling the lifter to learn and/or adapt quickly to physiological changes. The nervous system develops bidirectional pathways from the brain to the muscle and from the muscle to the brain (Yessis, 1981). After a period of time the nervous system actually becomes inhibited and further gains will not occur. Exercise programs must change at this point because there must be an activity overload in order to develop strength. By increasing intensity, volume, and duration, the nervous system will respond with renewed excitability. If the programs remain static for more than several weeks or months, the nervous system will respond at a lower level and physiological gain will not occur (Yessis, 1981).

O'Shea (1979) stated that as a result of isotonic, full range, multiple joint strength training, the neuromuscular system changes in the following manner:

1. There is an increase in the nerve fiber diameters.

2. There is an increase in the length of the motoneuron which provides a greater synaptic area for the effective release of neurotransmitters.

3. There is an increase in the size of the neuromuscular junction in proportion to muscle fiber type.

4. There is an increase in the motor endplate area which expands in proportion to an increase in axon length in the hypertrophied muscle.

5. There is an increase in the number of functional synapses which allow the athlete to utilize a greater percent of the motor units.

6. There is an increase in neuron facilitation and spatial summation. Voluntary motoneuron recruitment patterns are enhanced and modified by way of selective facilitation development.

Stone and Garhammer (1981) showed that positive changes occurred in the force-velocity relationship of muscular action of individuals who trained with free weights. The authors concluded that free weight exercises were needed to emphasize high force and high speed movements. These methods are considered crucial in power training as more fast twitch motor units are recruited.

Garhammer (1982) pointed out that free-standing total body lifts coupled with free weights, trained the neuromuscular system and resulted in excellent transfer to the neuromuscular demands of athletic competition. Many studies agreed that the use of Olympic lifts (Garhammer, 1982; Meyer, 1983; O'Shea & Wegner, 1981) and squat (O'Shea, 1979, 1985a; Wathen & Shutes, 1982) exercises can lead to effective development of strength and power.

Weight Training Effects on Strength and Power

Strength Development

Research has established that weight training can improve strength development which, in turn, increases power. There are two methods used to achieve an effective increase in muscular force or strength: (a) an increase in work intensity or (b) application of the progressive overload principle that incorporates specificity and variety.

The important factors in weight training programs are intensity, volume, frequency, duration, the type of exercise, and variation. The most important factor may be training specificity (Stone, 1982).

Berger's study (1962b) determined that changes in dynamic strength were greater when dynamic strength training took place. Static strength increased significantly more when static strength training occurred. The results demonstrate training specificity effects.

Sale (1986) summarized the specificity of training effects as follows:

1. Increases in voluntary strength are due to the type of muscle contraction in the training program.

2. Increases in voluntary strength occur at the targeted joint position through isometric strength training.

3. Increases in high velocity strength occur through training with high velocity contraction.

4. Strength training effects may be specific to limb exercise with unilateral or bilateral performance.

Specificity of training occurs through progressive resistance exercises (PRE) which increase the load or resistance as the muscle becomes stronger. In this training program strength quality is changed through the key factor, intensity. Intensity is based upon the selection of repetitions and sets as well as the workload or resistance utilized for each exercise.

DeLorme and Watkins (1948) introduced the concept of isotonic or dynamic weight training with a certain number of sets and repetitions. The authors' original strength training program involved three sets of ten repetitions with 50%, 75%, and 90% of maximum workload in each set, respectively. The program progressed from a set of 50% 10-RM to a set of 75% 10-RM and finally to a set of 90% 10-RM. The weight was increased until the subject could perform the 10-RM weight easily. DeLorme-Watkins' progressive resistance became the foundation of strength training programs.

Early in 1962, Berger conducted several studies with different combinations of sets and repetitions to determine the most effective weight training program for improving strength. In his first study (1962a) Berger showed that three sets of 6-RM three times a week produced greater increases in muscle strength. Later Berger (1962c) found that the optimum number of repetitions for increasing strength lay between three to nine when training with one set, three times a week. Berger (1962d) reported that training with submaximal loads of 90% was just as effective for increasing strength as training with maximum workloads.

Further investigation by Berger (1963) found no significant differences among three training programs utilizing two, six, and ten repetitions per set. Another study, Berger (1965), indicated that training with 66% of the 1-RM for one set, three times a week for six weeks, did not increase muscular strength. O'Shea (1966) found no significant differences among three training programs performing 2-RM, 6-RM, or 10-RM per set. Withers (1970) conducted a similar study and also found no significant differences among three training programs using 3-RM, 5-RM, or 7-RM per set.

In a review paper, O'Shea (1979) concluded that three types of programs develop muscle strength and endurance. The three programs are: (a) three sets of one to three repetitions at 90% of 1-RM to develop maximum strength; (b) four to five sets of four to ten repetitions at 75-85% of 1-RM for strength plus muscular endurance development; (c) five to seven sets of eight to ten repetitions at 60-75% of 1-RM for the development of muscular endurance. These programs are summarized and showed in Table 2.1.

Table 2.1

Weight training intensity.

Training Phase	Workload % of 1-RM	Reps	Sets
Maximum strength	90^{+}	1-3	3
Strength plus muscular endurance	75-85	4-10	4-5
Muscular endurance	60-75	8-10	5-7

Power Production

In more scientific terms, power is the rate at which work is performed. It is the amount of work undertaken during a given period of time. It is calculated simply as the product of force and speed (Bauer, 1986; Johnson & Nelson, 1986; Sapega & Brillings, 1983; Poprawski, 1987; Westcott, 1987). Work/Time is equivalent to force x velocity or strength x speed as an equation for power. The concept of power has been adapted to the human body which functions through muscular contraction. In the typical human, athletic power is the output from muscular contractions which produce force over a given distance in a period of time or at a specific limb velocity or speed. Therefore power is measured through muscular strength x limb velocity (Bauer, 1986).

O'Shea (1979) stated that power and strength are interrelated. To develop high power, the athlete needs to emphasize both strength and speed in the training program.

Garhammer (1982) explained the training effect as a relationship between force and velocity. There is evidence to suggest that strength training can shift the force-velocity curve to the right in beginners. Since power is equal to force times velocity, an increase in power occurs at all points on the curve. It appears that continuous training will force the lower portion of the curve to the right.

O'Shea (1979, 1985a) stated that rotary hip action is required by many kinds of sports such as running, jumping, lifting, throwing, blocking, or tackling. Thus the athlete utilizing these skills needs a strong "power zone" in order to perform effectively and safely. The muscle groups encompassing the body power zone are the lower back, hips, buttocks, and thighs. To maximize these muscle groups requires parallel squat training through a wide full-range joint movement. These exercises must be done with speed using fairly heavy resistance (approximately 25-30% of maximum speed).

Several studies have been conducted to investigate the effect of weight training on power. Published findings indicate that weight training groups tend to gain significantly in power (Capen, 1950; Chui, 1964).

Berger (1963) found that dynamic training groups improved more in the vertical jump than static training groups. Other studies by

Berger and Henderson (1966) and McClements (1966) indicated that the relationship between leg power and both static and dynamic leg strength were highly significant, but there was no significant difference from group to group. The strength development program tended to significantly increase flexion strength, extension strength, and power.

Flood (1970) conducted a study to investigate the effects of power weight training on power production. The conventional weight training group performed five selected exercises in two sets of six to eight repetitions, and two exercises in two sets of 15 repetitions. The power training groups performed a single 1-minute bout at each training session. A two minute rest occurred between each exercise bout. The results showed that both groups improved significantly in power as measured by vertical jump tests.

Christian and Seymour (1985) conducted a 10-week strength-power training program emphasizing the concepts of periodization on training procedures. The results indicated that the time required to reach peak power was always lower following the training program. Post-training appears superior for power production over the duration of the power test.

The most effective means of developing muscle force is high intensity and low volume strength and power training. More strength means more power, and greater power leads to greater success in terms of athletic performance (Westcott, 1987). With respect to evaluating muscular power, output points to the vertical jump as the best representation of fast performance, as well as forceful and propulsive movement. The vertical jump, therefore, may be the most appropriate test for power (Semenick, 1984).

One of the most important scientific considerations in the development of strength and power is periodization or cycle training. Periodization refers to the scheduled and highly organized athletic training programs that lead to peak competition. This method consists of macro-, meso- and micro-training cycles. The macro-cycle is comprised of a multi-year (one to three years) schedule, whereas the meso-cycle consists of yearly training with four phases: (1) general preparation, (2) specialized preparation, (3) competition, and (4) post-competition. Finally the micro-cycle includes weekly training consisting of four days a week (Auferoth, 1986; Pauletto, 1985; Yessis, 1982). The periodization concept originates from Matveyev (in Stone et al., 1981, 1982) who introduced the training concepts of specificity, overload, progression, and variety. This method was designed to prevent overtraining in the athlete's physiological system and to bring about optimum performance (Stone et al., 1982).

Stone and others (1981, 1982) presented a theoretical model for strength and power training. The model is shown in Table 2.2. The five phases of the cycle depicted in the model are: (a) hypertrophy or basic conditioning, (b) basic strength, (c) strength and power, (d) peak or maintenance, and (e) active rest. The recommended training intensities were set for high volume at low intensity during hypertrophy, moderate volume at high intensity for basic strength, low volume at high intensity for strength and power, low

Table 2.2

A hypothetical model of strength training.

Preparation → Transition 1 → Competition → Transition 2

Phase	Hypertrophy	Basic Strength	Strength and Power	Peaking or* Maintenance	Active** Rest
Sets[X]	3 - 5	3 - 5	3 - 5	1 - 3	-
Reps	8 - 20	2 - 6	2 - 3	1 - 3	-
Days/Week	3 - 4	3 - 5	4 - 6	1 - 5	-
Times/Day	1 - 3	1 - 3	1 - 2	1	-
Intensity Cycle (weeks)***	2 - 3/1	2 - 4/1	2 - 3/1	-	-
Intensity	low	high	high	very high to low	very low
Volume	high	moderate to high	low	very low	very low

* Peaking for sports with a definite climax or maintenance for sports with a long season such as football.

** Participating in some other sports or occasionally your own.

*** Intensity Cycle - ratio of the number of heavy training weeks to light training weeks.

X Does not include warm up sets.

volume at very high intensity for peak or maintenance, and very low volume and intensity for active rest. This model is similar to the cycle program established by O'Shea (1979). O'Shea's cycle program for dynamic strength development is shown in Table 2.3.

Table 2.3

The cycle program for dynamic strength development.

Training Week	Work Load % of 1-RM	Reps	Sets
Heavy	80 - 100^{+}	1 - 3	4 - 5
Light	60 - 75	10 - 12	3 - 4
Medium	70 - 85	4 - 5	4 - 5

The program is divided into four weekly periods of heavy, light, and medium training using a varying 1-RM percentage for a given number of repetitions and sets. The original cycle program introduced by O'Shea included 1) four to five sets of one to three repetitions at 80-100^{+}% for heavy training; 2) three to four sets of 10 to 12 repetitions at 60-75% of 1-RM for light training; and 3) four to five sets of four to five repetitions at 70-85% of 1-RM for medium training.

McDonagh and Davies (1984) suggested that much of the initial strength gains originate from learning factors in the nervous system. Practice enhances neurological efficiency and more efficient use of available muscle tissue. The strength gains tend to be slower since they are largely due to muscle tissue development.

Westcott (1987) found in his strength development training studies that excellent strength results from training with one hard set of 8-12 repetitions per exercise for either three days a week or two days a week over an 8-week period. He concluded that many strength training participants increased strength by 40-70% during the first month but strength tended to decline rapidly during the second month.

Sale (1986), in a review paper, indicated that with a short period (five to eight weeks) of strength training, voluntary strength increased without increasing the intrinsic contractile force of the muscle.

Training specificity effects are linked to type, intensity, and duration of the training program. The frequency and duration of the training programs vary. The frequency of training largely depends on the sport event, but usually training periods of at least two to three days a week are highly recommended by most researchers (Hellebrandt, 1958; Huber, 1987; O'Shea and Wegner, 1981; Westcott, 1987). The duration of the training program should be long enough to acquire physiological adaptation. Studies (Hellebrandt, 1958; Stone et al., 1982) indicate that a minimum of five weeks or ten days are required for adaptations to take place. Many studies found that the greatest strength gains involved one to three hard sets of two to ten repetitions for each exercise (Berger, 1962a, 1962b; O'Shea, 1966, 1976; Withers, 1970; Westcott, 1987).

Plyometric Training Effects on Strength and Power

In past decade, plyometric exercise became popular among coaches in track and field. As a result, the exercises were incorporated into the techniques used in modern athletic training programs. Chu and Plummer (1984) gave a definition of plyometrics:

> Plyometrics are drills or exercises aimed at linking sheer strength and speed of movement to produce an explosive-reactive type of movement. The term is often used to refer to jumping drills and in depth jumping, but plyometrics can include any drill or exercise utilizing the stretch reflex to produce an explosive reaction (p. 30).

Plyometric exercise is based on the belief that a rapid lengthening of a muscle before a contraction will result in much stronger contractions. The more rapidly that the muscle is lengthened (eccentric), the greater the immediate development of concentric force (Huber, 1987). An increase in contractile strength is believed to be due to muscle spindle stretching. The stretching involves a myotatic reflex and leads to an increased frequency of motor unit discharge as well as to increased and numbers of activated motor units (Clutch, Wilton, McGown, & Bryce, 1983).

Verkhoshanski (1968) discussed the plyometric exercise that divided the depth jump into three phases. The first phase is called amortization (force absorption). It occurs as a result of rapidly stretching the lower body extensor muscles. The second phase is called reactive recovery. In this phase, muscles execute a reactive switch to overcome the initially positive vertical velocity. The third phase is active take-off; the extensor muscles contract to perform the jump. Verkhoshanski (1973) later suggested a plyometric technique called depth jumps which were very effective in the perfection of speed-strength abilities in athletes. A height of 0.80 meters and 1.10 meters were recommended to achieve maximum speed and dynamic strength, respectively.

Chu (1983, 1984) and Chu and Plummer (1984) suggested that plyometric training develops the neuromuscular system. That is, plyometrics act as a means of training the neuromuscular system to react quickly and forcefully during a stretch-shortening type of action. Effectively performed concentric contractions in plyometric exercises may lead to greater synchronous motor units activity and earlier recruitment of larger motor units via the myotatic reflex. The results of plyometric training may increase force products, as well as creating greater speed and greater speed-strength capabilities or power.

Bosco (1982) and Lundin and others (Roundtable--Part I, 1986 in p. 16) indicated that plyometric training raises the threshold of Golgi tendon organ activation. This, in turn, improves tolerance to increased stretch loads in the muscle. A greater tolerance to stretch loads may create a stronger stretch reflex so that greater stretching loads can be withstood.

It is well established that the best effects of plyometric exercises occur when they are incorporated into a good weight training program. Strength development is requisite prior to the use of plyometric exercises to acquire speed and strength. Santos (Roundtable--Part I, 1986) stated that "without a basic strength program, the legs or arms of the athlete simply will not be able to withstand the extreme forces generated by plyometrics" (p. 17). Combined weight training and plyometric training provides variety and is considered to enhance strength training carry-over to both linear and vertical power development.

The training program should follow traditional periodization concepts. After a basic conditioning and basic strength phase, plyometrics should be used throughout the cycle. The strength-power phase should emphasize moderate to high intensity and high volume plyometrics. The peaking or maintenance phase should utilize plyometrics with moderate to heavy intensity and light to moderate volume (Roundtable--Part II, 1986 in p. 20).

The effects of depth jumping will depend on the height of the descent jump, number of repetitions per set and number of sets per workout. Novkov (1987) suggested that the optimal jump height for body weight 70 to 90 kilograms is 70 centimeters. A height of 50 centimeters is considered optimal for body weight of 100 or more kilograms. This lower height will help to prevent injuries to the nervous and muscular system. He also suggested a four-week training cycle with jumps performed every other day and the height changed at every workout. The optimum set number is two to four with ten repetitions per set.

In nature, plyometric exercise is anaerobic and requires maximum contraction and effort with each repetition. Many studies recommend that plyometric exercise drills take place twice a week for a period of no longer than 20 minutes. Optimal results can be achieved with two to four sets of five to ten repetitions and at least three to five minute rests between each set (Roundtable--Part II, 1986 in p. 14-24).

Plyometrics is the application of various jumping drills which pre-stretch muscles, forcing a rebound action known as a stretch reflex (myotatic reflex). It is known that a concentric (shortening) contraction is much stronger when it immediately follows an eccentric (lengthening) contraction. This action increases neuromuscular tension. Plyometric training leads to improved power due to increased force and greater speed.

Squat Training Research

Published research studies indicate that squat training is effective in the development of strength. O'Shea and Wegner (1981) studied a group of 13 men and 13 women. The women ranged in age from 18 to 30 years and the men from 19 to 26 years. The subjects participated in a 7-week power lifting program using the bench press and full squat. The researchers found that both men and women had significant gains ($P < .05$) in bench pressing and squatting power when measured in absolute strength and in terms of the strength-to-body-weight ratio. The pre-test and post-test measurement showed that the women's scores were superior to the men's scores in the bench press and in the squat ($p < .05$).

Chung (1983) conducted a study concerning the effectiveness of ten weeks of motor psychophysics training on the development of dynamic muscular strength in male college athletes and non-athletes. The subjects were randomly assigned to either the experimental group (weight training plus motor psychophysics training) or the control group (weight training only). The control subjects performed the bench press and squat exercises, and the experimental group added motor psychophysics training. The training period extended over ten weeks with training sessions of 90 minutes twice a week. The results showed that there was a significant ($p < .05$) difference between the two groups. The ten weeks of combined weight training and motor psychophysics training had a significant effect on the development of bench press strength and squat strength.

Fry and Powell (1987) used 23 male collegiates at the University of Nebraska - Lincoln to study the effect of three different weight training modes on the muscle balance characteristics of the thigh. Subjects were divided into squat, hip sled, leg extension and curl, and control groups. All experimental groups trained three times a week for eight weeks. Hamstring/quadricep (H/Q) muscle balance characteristics were measured both isokinetically and isometrically with a Cybex II isokinetic dynamometer. Their findings indicated that there was no significant difference among groups. It was concluded that an 8-week training program did not result in significant differences in the H/Q thigh characteristics.

Plyometric Training Research

Plyometric training and its effects on the development of speed-strength or muscle strength and jump performance has been well established. However, very few studies have been conducted in power production. Herman (1976) investigated the effect of depth jump training on the vertical jump performance of college age males. Each subject performed 12 depth jumps twice-weekly for the first week and then the number of depth jumps was increased by two per week over the 5-week training program. The depth jumps were performed from heights of 0.75 and 1.1 meters as recomended by Verkhoshanski (1968). The results indicated no significance between pre-test and post-test vertical jump performance.

Miller (1982) studied twenty-four female physical education students who were randomly assigned to one of two groups. They had the same mean vertical jump score. Group A trained with plyometric exercises once a week for eight weeks. They performed five sets of ten repetitions of depth jumps from a height of 50 cm. Group B acted as a control. The results showed that there was a significant ($p < .01$) difference between the two groups. The group with training improved their vertical jump performance more than the control group.

Verkhoshanski and Tatyan (1983) investigated the influence of a combination of methods on the speed-strength capabilities of sportsmen during one training session. Three groups of 36 athletes participated in speed-strength exercises such as maximum vertical jumps, standing long jumps and triple jumps, etc. Group A performed all of the above mentioned exercises. Group B used the same exercises as group A but in reverse order. Group C performed a depth jump over the 12-week period. The results showed a significantly greater change in speed-strength levels of athletes in group C over and above that found in groups A and B. No differences were noted in speed-strength levels between groups A and B.

Adams (1984) found gains in muscular leg strength and power via depth jump from heights of 0.6 to 1.5 meters. Male and female secondary school students ranging in age from 12 to 17 were randomly assigned to six groups (N = 177). Each group was assigned a different height for the depth jumps, the height being 0.61, 0.75, 1.22, and 1.50 meters, respectively. A fifth group participated in vigorous activity requiring running and jumping while the sixth group, the control group, participated in activities requiring minimal jumping. The results indicated no significant difference occurred between vertical jump and standing long jump performance among the six groups.

Brown, Mayhen and Boleach (1986) determined the effect of ploymetric training on vertical jump performance in 26 male high school basketball players. They were randomly assigned to a training group or a control group. The training group performed depth jumps in three sets of ten repetitions three days a week for 12 weeks. The control group performed only regular basketball training. The results indicated that the two groups were not significantly ($p > .05$) different in vertical jump performance without arm assistance. The plyometric group significantly improved in the vertical jump with arm assistance ($p < .05$) over the control group.

Bedi, Cresswell, Engel and Nicol (1987) investigated the increase in jumping height when dropping from different heights of 0, 25, 35, 45, 55, 65, 75, and 85 cm respectively. The results indicated that there were no significant differences in the height of the vertical jump within the two experimental groups.

Combined Squat and Plyometric Training Research

Combined weight training, especially squat and plyometric training, and its effects on the development of strength, speed and power has not been investigated extensively. A few studies have been published in this area. Between 1976 and 1977, a study was conducted at the University of Jyvaskyla in Finland (Bosco, Komi, Pulli & Montoneu, 1982). Eight male and female athletes of the Finnish National Volleyball team participated in a sixteen month training program. Both groups trained five or six times a week with weight training three times a week. The men, however, added plyometric training three times a week. This extra training consisted of seven to nine sets of ten vertical depth jumps with four minute pauses between each set. The results indicated significant differences in the standing vertical jump and depth jump at a level of $p > .01$ and $p > .05$ respectively based on the two training programs.

Parcell (1977) conducted a study to investigate the effect of depth jump training and weight training on vertical jump performance among 45 college-age males. The subject were randomly assigned to either of two experimental groups or to a control group. Group A participated in a 6-week weight training twice a week and performed an additional two repetitions every week. Group B engaged in depth jump training twice weekly over six weeks, performing a depth jump from a height of 0.8 meters for the first three weeks and 1.1 meters for the last three weeks. Initially, two sets of ten repetitions were performed. Later two additional jumps per week were added. The control group was inactive. Results indicated that there was a significant difference among the three groups. The depth jump training increased vertical jump performance, whereas the half-squat did not.

Blattner and Noble (1979) studied 48 volunteer males who were randomly assigned to three groups. Group 1 trained with isokinetic exercises, Group 2 trained with plyometric exercises, and Group 3 acted as the control group. The isokinetic group performed leg presses for three sets of ten repetitions per set during each training session. The plyometric group performed depth jumps for three sets of ten repetitions per set from a height of 34 inches. Resistances of 10, 15, and 20 pounds were added beginning in weeks three, five, and seven respectively. The two training groups exercised three times a week for eight weeks. Results showed that both training groups improved significantly in vertical jump capacity. However, no significant difference existed between training groups.

Polhemus and Burkhardt (1980) compared the influence of combined conventional weight training and plyometrics, and conventional weight training alone on performance in the bench press, power clean, half-squat and military press. The three experimental groups trained with conventional weight training only, conventional weight training and plyometrics, and conventional weight training and additional load during plyometrics. The results showed that the conventional weight training and additional load during plyometrics increased in strength compared to the other two groups. Polhemus, Burkhardt, Osina & Patterson, (1980) conducted a similar study of design and found identical results. The authors found conventional weight training and plyometrics resulted in significant improvement in the vertical jump, standing long jump, and 40-yard days performance.

Clutch et al. (1983) conducted two experiments simultaneously. In experiment I, 12 male undergraduate students in beginning weight training classes exercised with weight training and three different jumping programs: (a) maximum vertical jump, (b) 0.3m depth jumps, and (c) 0.75m and 1.10m depth jumps. In experiment II, 16 male members of a weight training class and 16 male members of the volleyball team at Brigham Young University-Hawaii were divided into two groups. Group 1 lifted weights and performed 0.75 and 1.10m depth jumps. Group 2 only lifted weights. In experiment I, the results showed no significant differences among the three training regimes, but all training programs resulted in increased maximum squat strength, as well as increased isometric knee extension strength and vertical jump performance. In experiment II, group one made significant increases in vertical jump performance.

Blakey (1985) studied 31 university student volumteers who were randomly assigned to three groups according to jump height (1.1m = high, 0.4m = low and 0.0m = no height). Each group trained for eight weeks on a plyometric and weight training program. The results revealed no significant differences between groups. Furthermore there were significant interactions of leg strength and power. However, pre-test and post-test scores demonstrated significant gains in both strength and power for each group.

Gemar (1987) investigated the effect of weight training and plyometric training on leg power as measured by the vertical jump, standing long jump, and 40-meter sprint ability. The plyometric group drilled two times a week, the weight training group drilled three times a week for an 8-week period and the control group was inactive. The results showed the the gains by the treatment groups were significantly greater ($p < .05$) than those experienced by the control group, but no differences existed between the two treatment groups.

Summary

This literature review has provided evidence that free weight training using squat, bench press and dead lift is a key training method for muscular strength development. Plyometric training has also been shown to affect muscular strength and jump performance. Published research is lacking, however, in the area of squat training, and combined squat training and plyometric training for the development of both static and dynamic muscular strength, and muscular power production. Published papers on squat training, and combined squat and plyometric training point out the critical need for research in this area.

CHAPTER 3

METHODS AND PROCEDURES

Research was conducted at Oregon State University, Corvallis, Oregon in the winter of 1988. All testing was done in the Exercise Science Instructional Laboratory of the Department of Physical Education at Oregon State University.

Subjects

Fifteen healthy college male students and two healthy college female students were involved in this study. The students attended Oregon State University. Subjects were volunteers enrolled in an advanced power weight training class during the winter term, 1988. The subjects were randomly assigned to one of the two experimental groups: a squat group or a combined squat and plyometric group. Both groups met for 50 minutes on Tuesday and Friday. Subjects were presented with an informed consent sheet which outlined the experiment (see Appendix B). Subjects consented to the research by signing their names on the informed consent release form (see Appendix C).

A summary of the physical characteristics of the subjects is contained in Table 3.1 and Table 3.2

Table 3.1

Combined physical characteristics of subjects.

Variables	Mean	SD	Minimum	Maximum
Age (yr)	22.29	3.82	19.00	34.00
Height (cm)	177.74	7.61	158.50	189.50
Weight (kg)	79.68	11.64	59.50	101.00

Table 3.2

Physical characteristics differentiated by sex.

Variable	Sex	Mean	SD	Minimum	Maximum
Age (yr)	Male (15)	22.27	3.86	19.00	26.00
	Female (2)	22.50	4.95	19.00	34.00
Height (cm)	Male (15)	179.17	6.11	168.50	189.50
	Female (2)	167.00	12.02	158.50	175.50
Weight (kg)	Male (15)	81.80	10.54	63.00	101.00
	Female (2)	63.75	6.01	59.50	68.00

Experimental Design

A pre-test and post-test randomized groups design (Thomas & Nelson, 1985) was used in this study. Initial testing was administered during the second week of the course to determine the subject's strength and power status. Based on the strength and power values collected in the pre-test, subjects were first paired and then randomly assigned to either the squat or combined squat and plyometric group. Nine subjects trained only with squat exercises whereas eight subjects trained with combined squat and plyometric exercises. One subject withdrew from the squat and plyometric training program. The final testing was administered immediately after completion of the 6-week training program. The design matrix is presented in Table 3.3.

Table 3.3

A pre-test and post-test randomized groups design.

Group	Pre-test	Experimental Treatment	Post-test
Squat (9)	01	X	02
Squat-Plyometrics (8)	03	X	04

Training Procedures

For the 6-week experimental period the subjects were divided into two experimental groups. Group 1 performed squats only whereas group 2 performed a combined program of squat and plyometric training. No other type of leg training was permitted in either group for the duration of the study. All subjects participated in a 2-week basic-strength conditioning program. During this period, instruction was given as to the correct techniques for the squat lift described by O'Shea (1985a) and the plyometric drills described by Chu (1983). At the end of the 2-week conditioning period, each subject was tested for maximum squat performance (1-RM). The 1-RM was used as the baseline for the establishment of the workout program during the experimental period for both groups.

A biomechanical analysis of the parallel squat (O'Shea, 1985a) involves three segments: (a) ready position, (b) descent, and (c) ascent. The correct execution of each segment sequence is crucial in producing a strong, fluid, mechanically effective and safe squat movement. Correct execution of the squat is as follows:

(A) Ready position:

1. The bar is positioned across the shoulders with the load distributed over the mass of the back.

2. Hands are positioned on the bar as close to the shoulders as possible.

3. Head is up; the chest is out.

4. Shoulders are back; the back is flat with an arch at the base. The spinal erectors are in strong isometric contraction.

5. Feet are flat on the floor and spaced wider than shoulder width, with the toes turned out at approximately 30 degrees.

This facilitates the "stretch reflex" mechanism that produces a strong eccentric contraction in the flexor-dominant muscles involved in the descent (See Figure 1).

(B) Descent:

1. After inhaling deeply, the squat is executed in a slow and controlled manner (45 degrees per second descent), utilizing a strong eccentric contraction of the hip and quadricep extensors, to a position where the top of the thighs is slightly lower than parallel.

2. During the descent, one should avoid leaning the torso forward by keeping the hip under the bar as much as possible. The greater the forward lean, the greater is the hip extension torque and reduced thigh extension torque (See Figures 2 and 3).

(C) Ascent:

1. The transition from the descent to the ascent which utilizes strong quadricep extension, commences with a powerful drive to accelerate out of the bottom position.

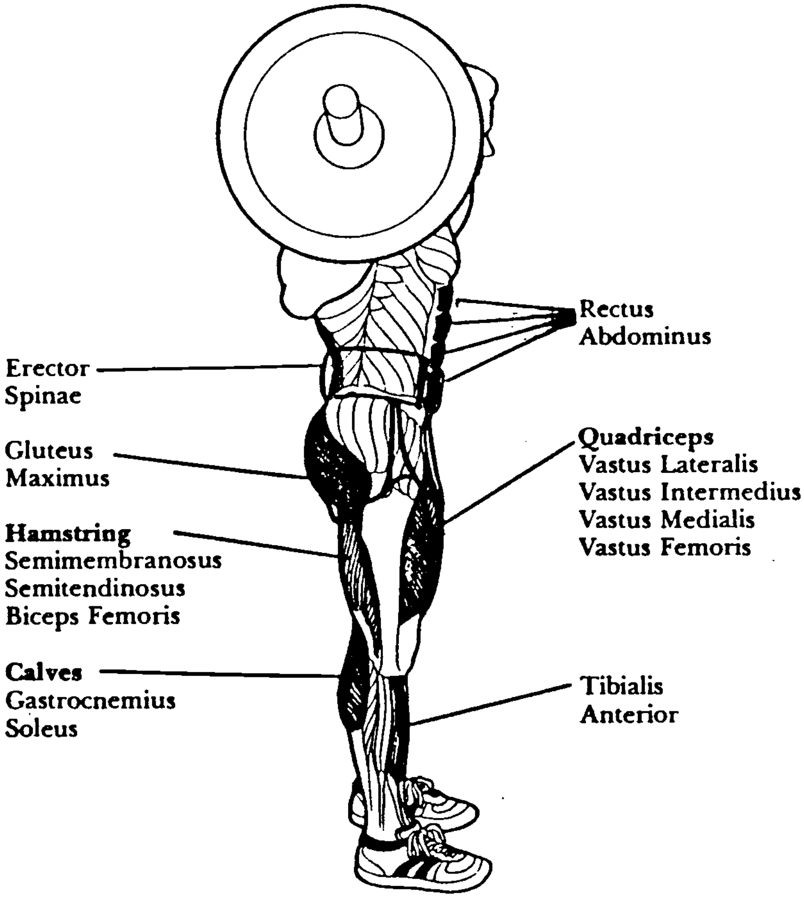


Figure 3.1 Starting position of the high bar squat.

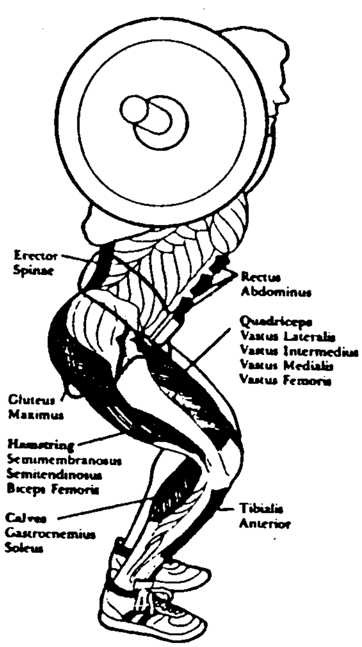


Figure 3.2 Middle position of the high bar squat.

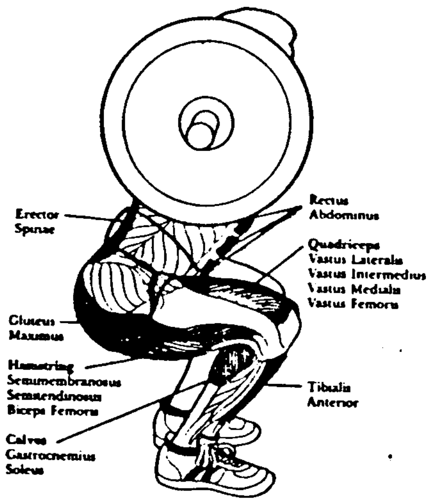


Figure 3.3 Bottom position of the high bar squat.

2. A tight torso is maintained throughout the ascent until knee lock is achieved in the standing position.

3. Kinetic energy helps provide the muscular force necessary to accelerate out of the bottom position (Force-Velocity relationship at work).

Training Protocol

For this study, a 6-week micro-periodization program was utilized (see Table 3.4 and Table 3.5). Three 2-week training cycles were used beginning with the conditioning phase, followed by the strength phase, and concluding with the strength and power phase. The training focus of each phase was as follows:

Phase I (Weeks 1 and 2)--Basic Conditioning

During this phase, the squat group used 70% of its capacity (see Table 3.4). This percent was not based on the subject's 1-RM but on the amount of weight the subject could handle at that time in the cycle. This group performed ten repetitions in three sets, twice a week. The workout schedule consisted of a 5-minute overall warm up followed by a specific warm up for squatting--two sets of ten repetitions. The training session executed three sets of ten repetitions for squats followed by 5-minute cool down (see Appendix A).

The plyometric group performed identical exercises to the squat group except that the training session involved only two sets of ten repetitions during the squat training phase (see Table 3.5). The group was then given a 5-minute rest prior to the plyometric training. Each depth and box jump was executed for five repetitions within two sets with a 3-minute rest between each set (see Appendix A).

Phase II (Weeks 3 and 4)--Basic Strength

The same training protocols were followed in Phase II except that intensity was increased. All subjects were required to lift 80% of their 1-RM. The squat group performed three sets of five repetitions (see Table 3.4). The plyometric group performed two sets of five repetitions for the training squat phase and took a 3-minute rest prior to plyometric training (see Table 3.5). Each depth and box jump was executed for five repetitions within each of three sets with a 1-minute rest between sets (see Appendix A).

Phase III (Weeks 5 and 6)--Strength and Power

The training intensity for the squat was increased to 90% of the 1-RM for two repetitions in each of three sets. This phase consisted of a split program of heavy and light days. In this study, Tuesday was a relatively heavy day while Friday was considered a light day. On Tuesday, the squat group was required to warm up by performing one set of squats for ten repetitions, followed by two sets of squats for five repetitions (see Table 3.4). This group performed squats with 90% of their 1-RM for three sets of three repetitions. On Friday, a light day, the workout was set at 80% of the 1-RM for three sets of three repetitions.

The plyometric group had an identical training schedule except that the training session involved only two sets of two repetitions in the training squat phase (see Table 3.5). This group was then given a 3-minute rest prior to the plyometric training. Each depth and box jump was executed for seven repetitions within each of three sets with a 1-minute rest between sets.

Table 3.4

Workout schedule for the 6-week squat training program.

Phase (week)	Workout poundage	Set*		Reps
Conditioning phase				
(1-2)	70% of capacity for	3	x	8-10
Strength phase				
(3-4)	80% of 1-RM for	3	x	5
Power phase				
(5-6**)	90% of 1-RM for	3	x	3

* did not include warm-up sets.

** Split program in week 5 and 6
- Tuesday 90% of 1-RM for 3 x 3
- Friday 80% of 1-RM for 3 x 3

Table 3.5

Workout schedule for the 6-week combined squat and plyometric training program.

Phase (Week)	Workout	Sets*		Reps
Conditioning phase				
(1-2)	Squat - 70% of capacity for	2	x	10
	Plyometrics			
	- Depth jumps (.71 meters)	2	x	5
	- Box jumps (.71 meters)	2	x	5
	3-minute rest between sets			
Strength phase				
(3-4)	Squat - 80% of 1-RM for	2	x	5
	Plyometrics			
	- Depth jumps (.71 meters)	3	x	5
	- Box jumps (.71 meters)	3	x	5
	1-minute rest between sets			
Power phase				
(5-6)	Squat - 90% of 1-RM for	2	x	2
	Plyometrics			
	- Depth jumps (.71 meters)	3	x	7
	- Box jumps (.71 meters)	3	x	7
	1-minute rest between sets			

* did not include warm-up sets.

Safety precautions

Due to the intensity and stress imposed by heavy squatting, specific safety measures were taken during the experimental period to reduce the possibility of injury. The precautions were undertaken according to O'Shea (1976):

1. Every training session was closely supervised.

2. Training was never done alone.

3. Correct techniques were used in all exercises.

4. Every experimental workout started and ended with free and stretching exercise movements for the lower back muscles.

5. Two or more spotters were present at all times.

6. All subjects were required to wear a lifting belt to provide added support to the lower back and abdominal muscles.

There were no injuries during the entire experimental period.

Instrumentation

The following instruments were utilized during data collection:

1. An automatic performance analyzer was used for measuring and recording the jump time required to complete vertical power jumps. This is a solid state digital read out timer calibrated in milliseconds and accurate to 1 millisecond (Instruction Book: Automatic Performance Analyer, 1985).

2. A cable tensiometer was used for measuring and recording the static leg strength. This test has reliability, validity, and an objectivity coefficient in order to obtain a subject's static leg strength (Johnson & Nelson, 1986). Cable tensiometer calibration was checked by the Engineering Department at Oregon State University, May 1987.

3. A goniometer was used to establish the correct angle of the knee joint in the static leg strength test (Johnson & Nelson, 1986).

4. A Cybex II dynamometer was used for measuring and recording the dynamic leg strength and power. This machine consisted of a dual channel and an exerted table. The dynamometer used in the study held the body to constant rates of limb velocity irrespective of the magnitude of the force generated by the participating muscles. The Cybex II dynamometer measures the torque in foot·pounds (ft·lb) and angular velocity in degrees per second (deg/sec). These units were transformed to Newton·meters (N·m) and radians per second (rad/sec) respectively. Both measures can be used to calculate power in watts (W). The Cybex II dynamometer (Cybex, Division of Lumax, Inc., Rankonkoma, NY, 11779) was calibrated according to the publication manual and was checked for correct torque and velocity calibration in December 1987.

Testing Procedures

The power tests and strength tests were administered before and after 6 weeks of training. Testing procedures were carefully explained and demonstrated to the subjects. Testing began first with the vertical power jump performance, which was followed by static leg strength measurement. Testing concluded with dynamic leg strength and power measurement.

Selection and Administration of Power Tests

Leg and hip power were assessed by means of the vertical jump and Cybex II dynamometer.

In testing vertical power jump performance, the procedures for measuring the explosive power followed Costill, Miller, Myers, Kehoe and Hoffman (1968); Johnson and Nelson (1986); and Poprawski (1987).

The subject initially stood with one side toward the wall, heels together, holding a piece of chalk in the hand nearest the wall. The subject reached as high as possible with his heels touching the floor, and made a mark on the wall. The subject performed three jumps from the 3/4 squat position, jumping upward to attain a maximum reach-height with one hand and then making a mark on the wall. The score was derived by taking the difference between jump reach-height and standing reach-height. Measurement was taken to the nearest half centimeter. The mean of the two closest trials was used in the analyses.

For a meaningful power measurement, the height score on the vertical jump, the time required to complete the jump (jump time), and the weight of the jumper can be transformed into units of power (kilogram·meters per second) (Johnson & Nelson, 1986; Poprawski, 1987). During vertical power jump performance a switch mat measured the jump time between take off and landing. The subjects stood on the switch mat and jumped vertically as high as possible. The timer started when the subject left the switch mat. The timer stopped when he landed. Time was measured in 0.001 seconds (Clutch et al., 1983). Three trials were given; the mean of the two closest trials was used in analyses.

Power testing for the quadricep and hamstring leg extensor and flexor muscle of the left leg followed protocol established by Dibrezzo, Gench, Hinson and King (1985); Francis and Hoobler (1987); and MacDougall et al. (1982).

Maximal contractions of the quadriceps and hamstrings were measured with speeds set at 30 degrees per second. The 90 degree position angle scale and a 360 ft·lbs torque range scale were selected. The zero torque baseline was checked momentarily by switching the chart speed to 25 mm/sec and adjusting the baseline as necessary.

The UBXT (Upper-Body Exercise and Test Table) was adjusted and attached to appropriate stabilization accessories. The subject was positioned on the UBXT. The left leg was stabilized with a strap at midthigh to provide for alignment of the anatomical axis of rotation of the knee joint with the rotational axis of the dynamometer. The ankle was secured to the lever arm using the tibial pad or cuff. All subjects were instructed to grasp the handles on each side of the UBXT. These were located just proximal to the knee.

The subject was allowed five to seven practice trials of complete extension and flexion with the speed set at 180 degrees per second in order to warm up and to familiarize himself with the Cybex II. During the test period, subjects were instructed to complete a full range of motion as hard and as fast as possible. Three trials were given. After each trial, the subject rested for 10 seconds. The Cybex II recording displayed torque and angular velocity from which one can calculate power. Power is equal to the product of torque (N·m) and angular velocity (rad/sec), so that the proper units of power, namely watts (W), can be obtained. The mean of the two closest trials was used in the analyses.

Selection and Administration of Static Strength Tests

Static leg strength testing of the right leg extensor muscle was done in accordance with the testing protocol established by Clarke (1953); and Clarke and Munroe (1970).

The subject was instructed to sit on the table with his hands behind his hips and his elbows extended. A piece of webbed belting 2 inches wide was placed around the lower right leg midway between the ankle and knee joints. This was connected with "D" rings to a tensiometer. A goniometer was then used to measure the angle of the subject's knee; the angle of knee was positioned at 115 degrees of extension. An adjustable chain was used to hook the strain to the table. During testing, special attention was given to gradual tension development because any jerking movement on the tensiometer would result in loss of maximum force. The subject exerted a maximum force; three trials were conducted on the right leg. The subject was given 10 seconds to rest between trials (Clutch et al., 1983; Johnson & Nelson, 1986; MacDougall et al., 1982). Tension was determined from the tensiometer. This tension was converted directly into pounds from the calibration chart and then transformed to Newtons in SI units (American College of Sports Medicine, 1971). The mean score of the two closest trials was recorded and used for statistical analyses.

Dynamic strength testing for the quadriceps and hamstrings was done with the same protocol as the power testing. Testing utilized the Cybex II dynamometer.

Data Collection

In all strength and power tests, the best results of the two closest trials were selected as the measurements used for analysis.

To examine all possible expressions of the variables, the following conversion factors and transformations were made:

1. Use of a biomechanical power formula to convert vertical power jump scores into units of power (Johnson & Nelson, 1986; Poprawski, 1987):

$$P = \frac{BW \times D}{t}$$

where P = power in kilogram·meters per second

BW = bodyweight in kilograms

D = vertical jump reach-height in meters

t = jump time in seconds

2. Use of Newtonian physics and conversion factors to change the scale on the Cybex II dynamometer into units of strength and power (MacDougall et al., 1982):

2.1 Use of a calibration chart to change the scale on the Cybex II recording to foot·pounds (ft·lb).

1 square = 12 ft·lbs

2.2 Use of a conversion factor to transform "ft·lb" to "N·m" (units of dynamic strength or torque):

1 ft·lb = 1.355818 N·m

2.3 Use of a conversion factor to transform degrees to radians:

1 degree/sec = 0.017453 rad/sec

2.4 Use of a biomechanical power formula to convert the scale on the Cybex II recording into units of power:

$$P = T \times \omega$$

where P = Power in watts

T = torque in N·m

ω = angular velocity in rad/sec

3. Use of a calibration chart and a converting factor to change the tensiometer score into units of static strength (American College of Sports Medicine, 1971; MacDougall et al., 1982):

$$1 \text{ lb} = 4.448222 \text{ N}$$

4. Ratios of hamstring and quadricep strength to assess the balance strength level in these muscles (Fry & Powell, 1987; Morris, Lussier, Bell & Dooley, 1983).

5. Ratios of the amount of force produced on the cable tensiometer and the Cybex II dynamometer to body-weight to assess relative strength levels (Kirkendall, Gruber & Johnson, 1987).

Test Design

The eight dependent variables tested in this study were:

1. jump height,
2. jump time,
3. vertical power jump,
4. static leg strength,
5. dynamic leg strength,
    5.1 hamstring strength,
    5.2 quadricep strength,
6. relative strength,
7. hamstring/quadricep strength ratio, and

8. hamstring and quadricep power.

The two independent variables were squat and combined squat and plyometric training.

Data Analyses

Appropriate statistical techniques were used to analyze the data. The mean, standard deviation, minimum, and maximum values for the subjects' physical characteristics provided a descriptive overview.

A *t*-test for paired comparisons (correlated data) was computed on each dependent variable within each group to determine whether the change which took place in each group was significant.

A repeated measures analysis of variance (ANOVA) used to determine the amount of change in test score means for strength and power between the squat group, and the combined squat and plyometric group. The pre-test and post-test values represented the average mean scores (Thomas & Nelson, 1985; Stamm & Safrit, 1975).

A .05 level of significance was used for all statistical tests.

Two statistical packages were used for analyses. SPSSX (SPSS, 1986) was used for the *t*-test and BMDP (Dixon, Brown, Engelman, Frane, Hill, Jennrich & Toporek, 1983) was used for the repeated measures (ANOVA). The statistical programs were run on the CYBER Mainframe computer in the Milne Computer Center at Oregon State University.

CHAPTER 4

RESULTS

The objective of this study was to determine the relative effectiveness of a six week strength training program consisting of squat and plyometric exercise on vertical power jump performance, static and dynamic muscular strength, and muscular power. The changes in all variables were analyzed statistically using a *t*-test for paired (correlated) data, and repeated measures analysis of variance (ANOVA). Test scores are contained in Appendix E.

The results of this study are presented under the subheadings: (a) vertical power jump, (b) quadricep and hamstring power, (c) static leg strength, (d) dynamic leg strength, (e) relative strength, and (f) hamstring/quadricep strength ratio.

Vertical Power Jump

The body weight, jump height and jump time were variables used to measure leg power in the vertical power jump test.

Body weight

The purpose of this analysis was to determine if there were significant differences due to body weight between the squat group, and the combined squat and plyometric group after a six week training period. Analysis of variance results given in Table 4.1 show changes in body weight between the two training programs. The values resulted in no significant *F* ratio for the groups by trials ($F = .15$) at the .05 level. Consequently, the null hypothesis was accepted. There was no significant difference between the two experimental groups in body weight, although the overall averaged scores demonstrated that body weight changed from the pre-test to post-test state.

The results of changes in body weight for each group are shown in Table 4.2. A paired t-test was applied to the pre-test and the post-test mean scores for each group. The t values computed for the body weight of the squat group, and the combined squat and plyometric group were 1.71 and 1.83 respectively. These values were not statistically significant at the .05 level. Figure 4.1 compares body weight pre-test means and post-test means for each group.

Table 4.1

Repeated measures ANOVA for body weight.

Source of variation	df	SS	MS	F	P
Between groups	1	269.672	269.672	1.05	.32
Within groups	15	3855.637	257.042		
Between trials	1	25.023	25.023	5.64	.03*
Groups by trials	1	.670	.670	.15	.70
Within trials	15	66.609	4.440		

* Significant at the .05 level.

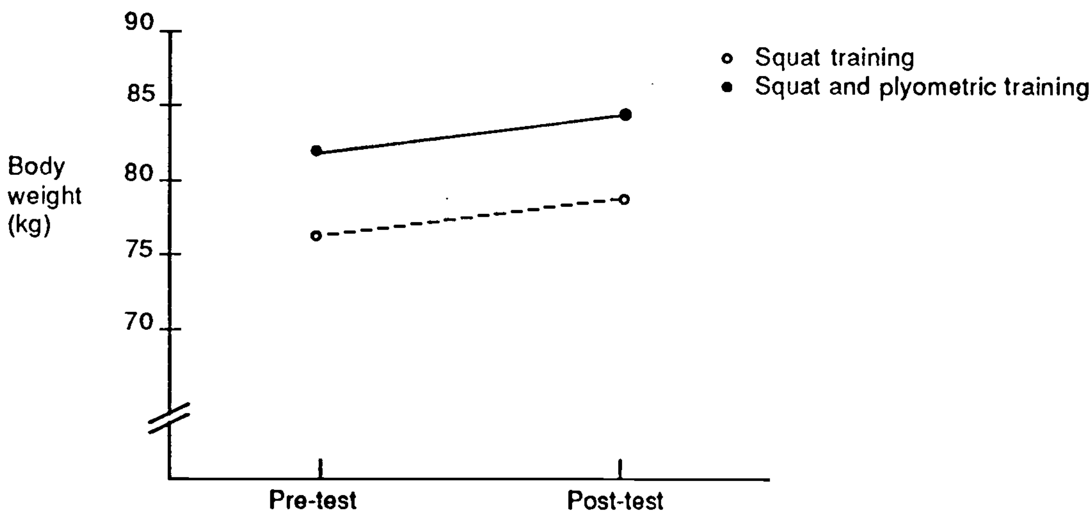
Table 4.2

Body weight changes with six weeks of squat, and combined squat and plyometric training.

Body weight (kg)	Squat			Squat/Plyometric		
	$\bar{X}$	SD	SE	$\bar{X}$	SD	SE
Pre-test	76.89	11.76	3.92	82.81	11.41	4.03
Post-test	78.89	12.68	4.23	84.25	9.40	3.33
Adjusted mean	81.50			81.30		
Difference mean	2.00			1.44		
Percentage change	2.60			1.74		
t	1.71			1.83		
P	.13			.11		

Figure 4.1

Body weight pre-test and post-test mean scores.



Jump Height

A statistical analysis was conducted to determine if there were significant differences between the squat group, and the combined squat and plyometric group with respect to jump height. Analysis of variance results are given in Table 4.3. The results show no significant F ratio for the groups by trials (F = .23) at the .05 level. Consequently, the null hypothesis was accepted. Although there was no significant difference between the two experimental groups in jump height, overall averaged scores indicated that the jump height changed from the pre-test to the post-test state.

The results of changes in jump height for each group are reported in Table 4.4. A t-test was utilized to compare the pre-test mean and the post-test mean for each group. The t values computed for the jump height of the squat group, and the combined squat and plyometric group were 2.16 and 2.14 respectively. These statistics indicated no significant difference at the .05 level with respect to jump height for either group.

The graph in Figure 4.2 compares the jump height pre-test means and post-test means for each group.

Table 4.3

Repeated measures ANOVA for jump height.

Source of variation	df	SS	MS	F	p
Between groups	1	34.473	34.473	.29	.60
Within groups	15	1790.762	119.384		
Between trials	1	200.450	200.450	8.62	.01*
Groups by trials	1	5.450	5.450	.23	.64
Within trials	15	348.609	23.241		

* Significant at the .05 level.

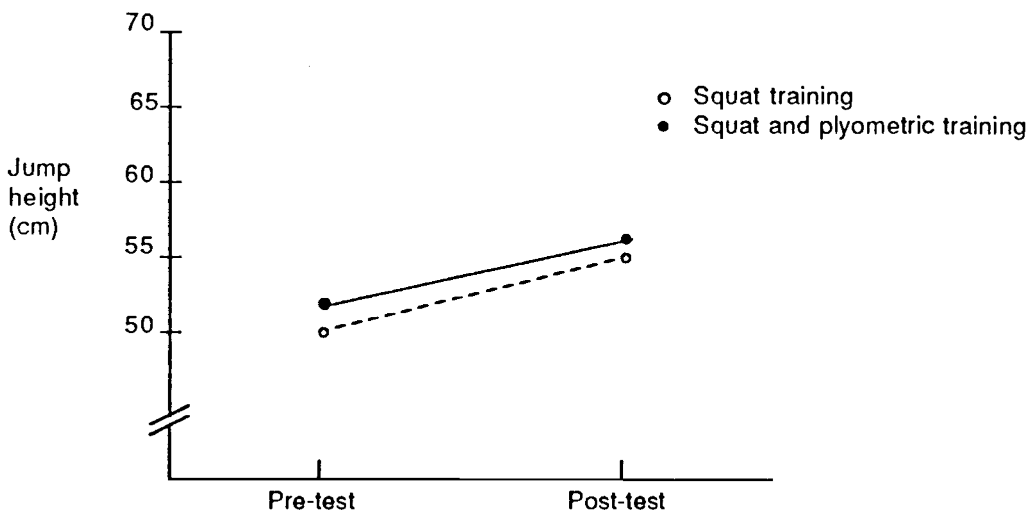
Table 4.4

Jump height changes with six weeks of squat, and combined squat and plyometric training.

Jump height (cm)	Squat $\bar{X}$	SD	SE	Squat/Plyometric $\bar{X}$	SD	SE
Pre-test	50.06	7.65	2.55	52.88	6.24	2.21
Post-test	55.72	10.37	3.46	56.94	8.78	3.10
Adjusted mean	57.01			55.01		
Difference mean	5.67			4.06		
Percentage change	11.33			7.68		
t	2.16			2.14		
P	.06			.07		

Figure 4.2

Jump height pre-test and the post-test mean scores.



<u>Jump Time</u>

ANOVA was used to assess differences with respect to jump time increases between the squat group, and the combined squat and plyometric group after a six week training period. The test resulted in a computed F value of .82 (see Table 4.5). This figure was not significant at the .05 level. Consequently, the null hypothesis was accepted. There was no significant difference between the two experimental groups in jump time.

Table 4.6 illustrates that in jump time, the squat group increased its jump time. The squat group pre-test level jump time of .59 seconds increased to a post-test level of .62 seconds, a gain of .03 seconds (5.08%). A paired t-test analyzed the pre-test mean scores and the post-test mean scores for each group. The t values computed for the jump time of the squat group, and the combined squat and plyometric group were 2.32 and .35 respectively. A significant difference at the .05 level was found in the squat group. This finding indicated that the jump time changed significantly in the squat group, while it did not change significantly in the combined squat and plyometric group.

The graph in Figure 4.3 shows the jump time pre-test means and post-test means for each group.

Table 4.5

Repeated measures ANOVA for jump time.

Source of variation	df	SS	MS	F	p
Between groups	1	8.672	8.672	.18	.68
Within groups	15	734.516	48.968		
Between trials	1	21.459	21.459	2.34	.15
Groups by trials	1	7.511	7.511	.82	.38
Within trials	15	137.468	9.165		

Table 4.6

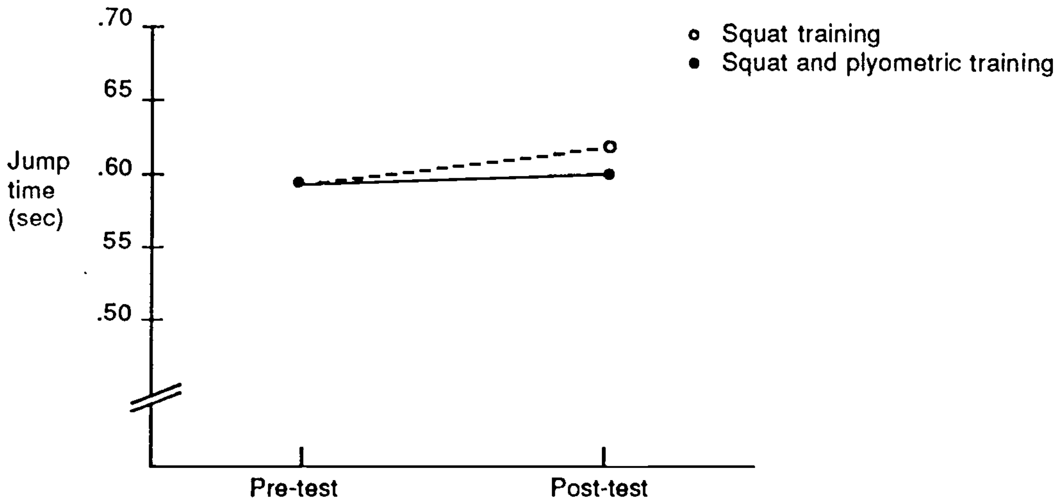
Jump time changes with six weeks of squat, and combined squat and plyometric training.

Jump time	Squat			Squat/Plyometric		
(sec)	$\bar{X}$	SD	SE	$\bar{X}$	SD	SE
Pre-test	0.59	0.05	0.02	0.59	0.05	0.02
Post-test	0.62	0.05	0.02	0.60	0.06	0.02
Adjusted mean	0.62			0.60		
Difference mean	0.03			0.01		
Percentage change	5.08			1.69		
t	2.32			0.35		
P	.05*			.73		

*Significant at the .05 level.

Figure 4.3

Jump time pre-test and post-test mean scores.



<u>Vertical power jump</u>

A statistical analysis was conducted to determine if there were significant differences in vertical power jump performance between the squat group, and the combined squat and plyometric group. ANOVA results show the change in the vertical power jump by the two training programs (see Table 4.7). The results revealed no significant <u>F</u> ratio (F = .29) at the .05 level. Consequently there was no significant difference between the two experimental groups in vertical power jump, although the averaged overall scores for the vertical power jump changed from the pre-test to the post-test state.

Table 4.7

Repeated measures ANOVA for vertical power jump.

Source of variation	df	SS	MS	F	p
Between groups	1	3328.032	3328.031	2.31	.15
Within groups	15	21596.558	1439.771		
Between trials	1	1177.196	1177.196	13.11	.00*
Groups by trials	1	25.753	25.753	.29	.60
Within trials	15	1347.900	89.793		

* Significant at the .05 level.

Table 4.8 shows that in the vertical power jump, the combined squat and plyometric group made a significant gain. The combined squat and plyometric group pre-test vertical power jump level of 147.64 kg.m/sec increased to a post-test level of 161.17 kg.m/sec, a gain of 13.53 kg.m/sec (3.06%). A paired t-test compared the pre-test mean scores and the post-test mean scores for each group. The t values computed for the vertical power jump of the two groups were 2.13 and 3.06 respectively. A significant difference at the .05 level was found for the mean gains in the combined squat and plyometric group. The vertical power jump performance changed significantly in the combined squat and plyometric group, while it did not change significantly in the squat group.

The graph in Figure 4.4 shows that vertical power jump changed from the pre-test mean to the post-test mean for the combined squat and plyometric group.

Table 4.8

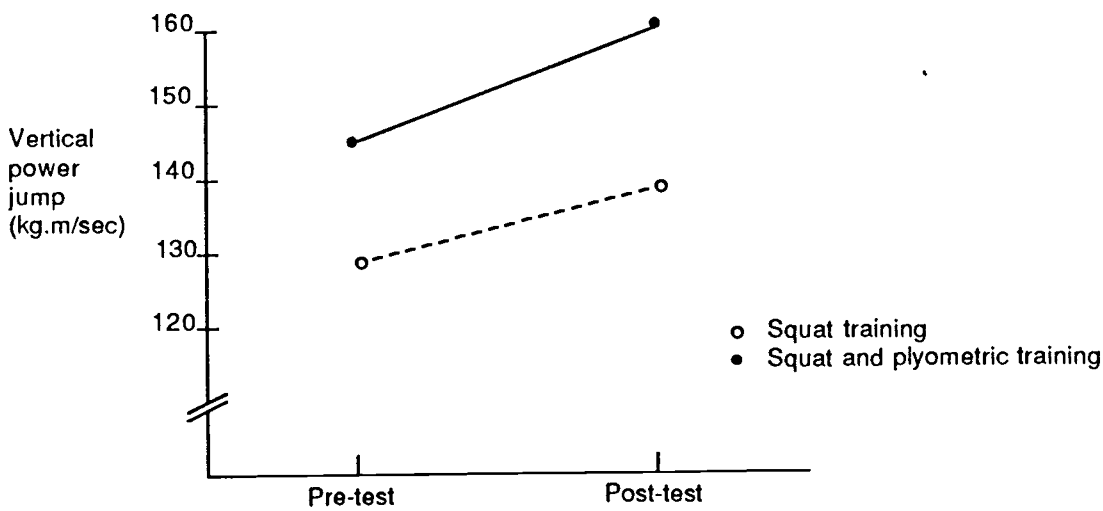
Vertical power jump changes with six weeks of squat, and combined squat and plyometric training.

Vertical power jump (kg.m/sec)	Squat			Squat/Plyometric		
	$\bar{X}$	SD	SE	$\bar{X}$	SD	SE
Pre-test	129.56	24.31	8.10	147.64	23.97	8.47
Post-test	139.61	26.88	8.96	161.17	34.67	12.26
Adjusted mean	149.45			150.09		
Difference mean	10.05			13.53		
Percentage change	7.76			9.16		
t	2.13			3.06		
P	.07			.02*		

* Significant at the .05 level.

Figure 4.4

Vertical power jump pre-test and post-test mean scores.



Quadricep and Hamstring Power

The left leg quadricep extensor and hamstring flexor muscle was used as an index of leg power. The Cybex II dynamometer measured leg power.

Quadricep power

A repeated measures ANOVA was utilized to determine whether there were any significant differences in quadricep power between the squat training, and the combined squat and plyometric training group. The results showed that the obtained *F* ratio (F = 1.44) was not significant at the .05 level (see Table 4.9) and the null hypothesis was accepted. That is, both experimental groups demonstrated nearly the same increase in quadricep power.

A paired *t*-test was applied to compare the pre-test means and the post-test means for each group. Changes in quadricep power for each group are shown in Table 4.10. The *t* values computed for the quadricep power of the squat group, and the combined squat and plyometric group were .29 and 1.19 respectively. The results showed no significant difference for each group at the .05 level. Thus there was no significant change in quadricep power from the pre-test mean to the post-test mean for each group.

The graph in Figure 4.5 compares quadricep power pre-test means and the post-test means within each group.

Table 4.9

Repeated measures ANOVA for quadricep power.

Source of variation	df	SS	MS	F	P
Between groups	1	1395.864	1395.864	.91	.36
Within groups	15	23071.901	1538.127		
Between trials	1	182.655	182.655	.78	.39
Groups by trials	1	336.195	336.195	1.44	.25
Within trials	15	3503.887	233.592		

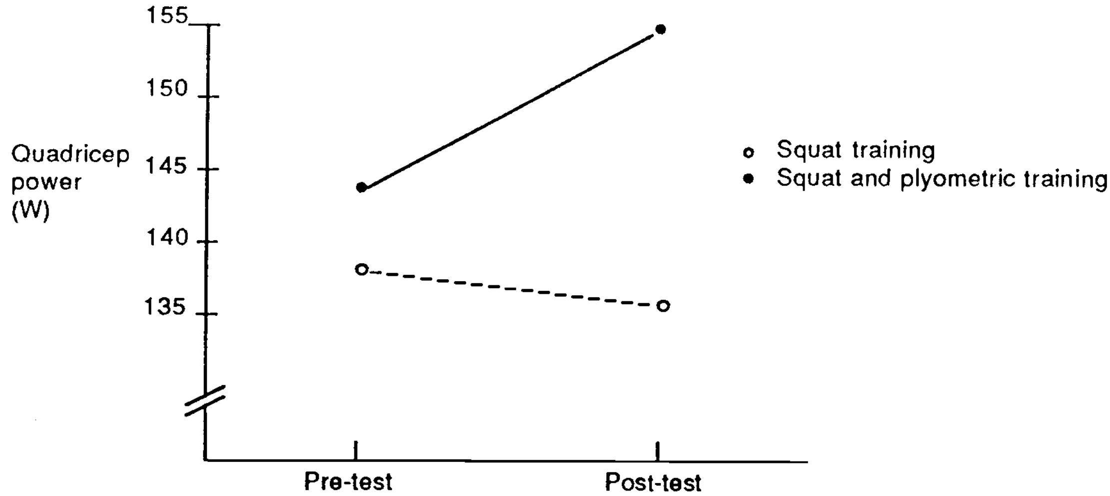
Table 4.10

Quadricep power changes with six weeks of squat, and combined squat and plyometric training.

Quadricep power (W)	Squat			Squat/Plyometric		
	$\bar{X}$	SD	SE	$\bar{X}$	SD	SE
Pre-test	138.19	29.44	9.81	144.73	32.00	11.32
Post-test	136.54	25.90	8.63	155.67	31.86	11.27
Adjusted mean	138.67			153.27		
Difference mean	1.66			10.94		
Percentage change	1.20			7.56		
t	.29			1.19		
P	.78			.27		

Figure 4.5

Quadricep power pre-test and post-test mean scores.



Hamstring power

ANOVA was conducted to determine whether there were any significant differences in hamstring power between squat training, and combined squat and plyometric training. The *F* ratio was not significant at the .05 level (see Table 4.11), and the null hypothesis was accepted. That is, there was no significant difference between the two experimental groups in hamstring power, although averaged overall scores in hamstring power changed from the pre-test to post-test level.

Table 4.12 shows that both the experimental groups increased in hamstring power. The squat group hamstring pre-test level of 64.84 watts increased to a post-test level of 71.23 watts, a gain of 6.39 watts (9.86%). The combined squat and plyometric group also increased 11.71 watts or 16.51% from the pre-test level to the post-test level. The *t* values computed for the hamstring power of the squat group, and the combined squat and plyometric group were

2.29 and 2.36 respectively. The results showed a significant difference at the .05 level in hamstring power for each group. Thus the null hypothesis was rejected. There were significant gains for both experimental groups of 6.36 and 11.71 watts respectively, between the pre-test and post-test means.

The graph in Figure 4.6 illustrates changes in hamstring power from the pre-test mean to the post-test mean within each group.

Table 4.11

Repeated measures ANOVA for hamstring power.

Source of variation	df	SS	MS	F	P
Between groups	1	632.049	632.049	1.31	.27
Within groups	15	7218.315	481.221		
Between trials	1	693.744	693.744	10.72	.01*
Groups by trials	1	59.979	59.979	.93	.35
Within trials	15	971.083	64.739		

* Significant at the .05 level.

Table 4.12

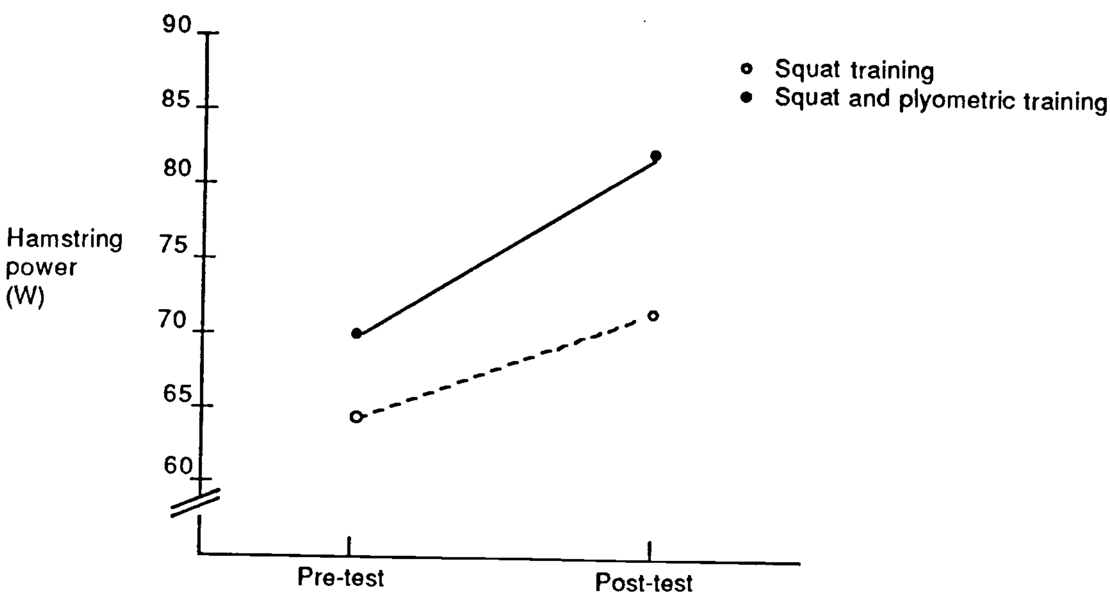
Hamstring power changes with six weeks of squat, and combined squat and plyometric training.

Hamstring power (W)	Squat			Squat/Plyometric		
	X̄	SD	SE	X̄	SD	SE
Pre-test	64.84	16.81	5.60	70.81	15.64	5.53
Post-test	71.23	19.44	6.48	82.52	13.07	4.62
Adjusted mean	73.43			80.03		
Difference mean	6.39			11.71		
Percentage change	9.86			16.54		
t	2.29			2.36		
P	.05*			.05*		

* Significant at .05 level.

Figure 4.6

Hamstring power pre-test and post-test mean scores.



Static Leg Strength

The maximum force of isometric muscle contraction as an index of right leg extensor static leg strength was measured by the Cable tensiometer.

ANOVA was used to assess differences with respect to static leg strength between the squat training group, and the combined squat and plyometric training group. The results showed that the obtained *F* ratio was not significant at the .05 level (see Table 4.13). Consequently, the null hypothesis was accepted. There was not a significant difference between the two experimental groups in static leg strength, although the averaged overall scores in the static leg strength changed from the pre-test to the post-test state.

Table 4.14 shows that the squat group decreased in static leg strength. The squat group static leg strength pre-test level of 900.02 Newtons decreased to a post-test level of 807.11 Newtons, a difference of 92.92 Newtons (10.32%). The combined squat and plyometric group also decreased by 40.31 Newtons (4.31%) from the pre-test mean to the post-test mean. The differences between the pre-test and the post-test means for both groups were compared using the t-test. The static strength *t* values computed for the squat group, and the combined squat and plyometric group were 10.32 and 1.06 respectively. The results showed a significant difference at the .05 level in static leg strength for the squat group. Consequently, the null hypothesis was rejected. Static leg strength decreased significantly in the squat group, while it did not decrease significantly in the combined squat and plyometric group.

Figure 4.7 shows that static leg strength changed from the pre-test level to the post-test level for the squat group.

Table 4.13

Repeated measures ANOVA for static strength.

Source of variation	df	SS	MS	F	P
Between groups	1	32639.035	32639.035	1.38	.26
Within groups	15	353948.958	23596.597		
Between trials	1	37589.105	37589.105	7.33	.02*
Groups by trials	1	5860.506	5860.506	1433	.31
Within trials	15	78064.617	5204.308		

* Significant at the .05 level.

Table 4.14

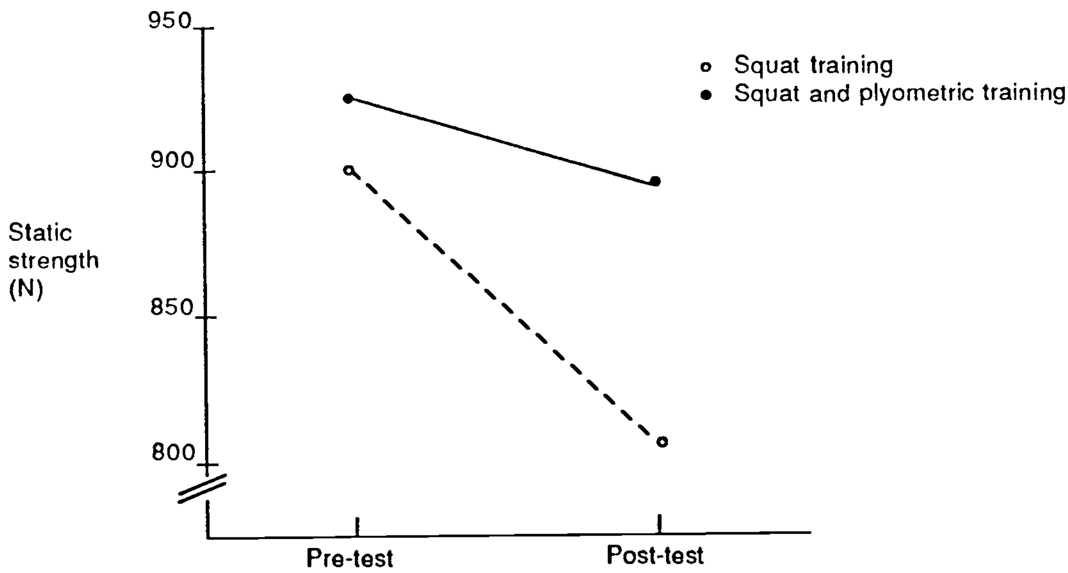
Static strength changes with six weeks of squat, and combined squat and plyometric training.

Static strength (N)	Squat			Squat/Plyometric		
	$\bar{X}$	SD	SE	$\bar{X}$	SD	SE
Pre-test	900.02	138.30	46.10	935.79	122.51	43.32
Post-test	807.11	79.42	26.47	895.48	132.81	46.96
Adjusted mean	816.10			885.36		
Difference mean	92.92			40.31		
Percentage change	10.32			4.31		
t	2.88			1.06		
P	.02*			.33		

* Significant at the .05 level.

Figure 4.7

Static strength pre-test and post-test mean scores.



Dynamic Leg Strength

The left leg quadricep extensor and hamstring flexor muscle were used as an indicator of dynamic leg strength based on Cybex II dynamometer measurements.

Quadricep strength

A statistical analysis was conducted to determine if there were significant differences between the squat group, and the combined squat and plyometric group for quadricep strength. The ANOVA results shown in Table 4.15 represent the change in quadricep strength according to the training programs. The results revealed no significant F ratio ($F = 1.44$) at the .05 level. Consequently, the null hypothesis was accepted. That is, both experimental groups demonstrated nearly the same increase in quadricep strength.

The differences between the pre-test and post-test mean for both groups were compared using the t-test. The results showed no significant difference at the .05 level in quadricep strength for each group. Therefore the null hypothesis was accepted. There was no significant change in quadricep strength from the pre-test mean to the post-test mean for each group. Figure 4.8 compares the quadricep strength pre-test means and the post-test means for each group.

Table 4.15

Repeated measures ANOVA for quadricep strength.

Source of variation	df	SS	MS	F	P
Between groups	1	5091.676	5091.676	.91	.36
Within groups	15	84159.076	5610.605		
Between trials	1	666.265	666.265	.78	.39
Groups by trials	1	1226.337	1226.337	1.44	.25
Within trials	15	12781.143	852.076		

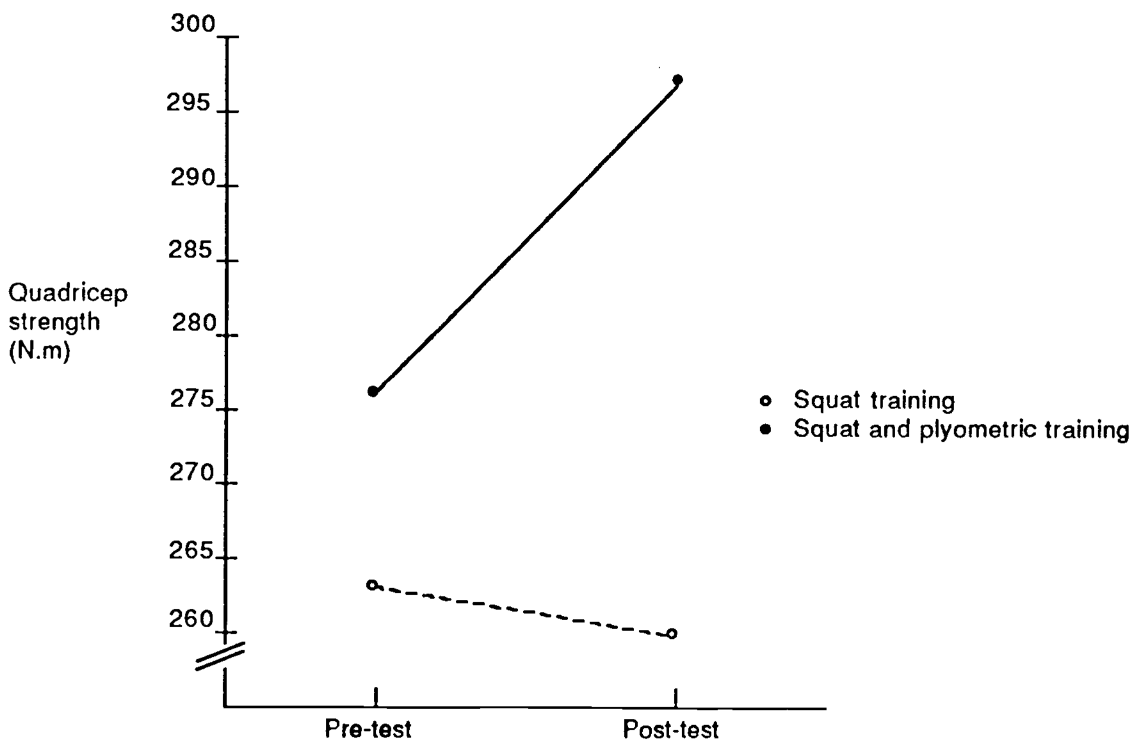
Table 4.16

Quadricep strength changes with six weeks of squat, and combined squat and plyometric training.

Quadricep strength (N·m)	Squat $\bar{X}$	Squat SD	Squat SE	Squat/Plyometric $\bar{X}$	Squat/Plyometric SD	Squat/Plyometric SE
Pre-test	263.93	56.23	18.74	276.42	61.12	21.61
Post-test	260.77	49.46	16.49	297.32	60.86	21.52
Adjusted mean	264.85			292.73		
Difference mean	3.16			20.90		
Percentage change	1.20			7.56		
t	.29			1.19		
P	.78			.27		

Figure 4.8

Quadricep strength pre-test and post-test mean scores.



Hamstring strength

A statistical analysis was applied to determine if there were significant differences between the squat group, and the combined squat and plyometric group for hamstring strength. ANOVA results shown in Table 4.17 present the change in hamstring strength between the two training programs. The results revealed no significant F ratio (F = .93) at the .05 level. Consequently, the null hypothesis was accepted. There was no significant difference between the two experimental groups in hamstring strength, although averaged overall scores in hamstring strength changed from pre-test to post-test levels.

Table 4.18 shows that both the experimental groups increased in hamstring strength. The squat group pre-test level of 123.83 N·m increased to a post-test level of 137.03 N·m, a gain of 12.20 N·m (9.85%). The combined squat and plyometric group also gained in strength, with a 22.38 N·m (16.55%) increase from the pre-test level to the post-test level. The differences between the pre-test and post-test means for both groups were compared using the t-test. The computed t values for hamstring strength of the squat group, and the combined squat and plyometric group were 2.29 and 3.36 respectively. The results showed a significant difference at the .05 level in hamstring strength for each group. Consequently, the null hypothesis was rejected. The significant gains for both experimental groups were 12.20 and 22.38 N·m respectively, between the pre-test and post-test means.

The graph in Figure 4.9 shows changes in hamstring strength from the pre-test mean to the post-test mean within each group.

Table 4.17

Repeated measures ANOVA for hamstring strength.

Source of variation	df	SS	MS	F	P
Between groups	1	2304.216	2304.216	1.31	.27
Within groups	15	26331.274	1755.418		
Between trials	1	2531.972	2531.972	10.72	.01*
Groups by trials	1	219.189	219.189	.93	.35
Within trials	15	3541.707	236.114		

* Significant at the .05 level.

Table 4.18

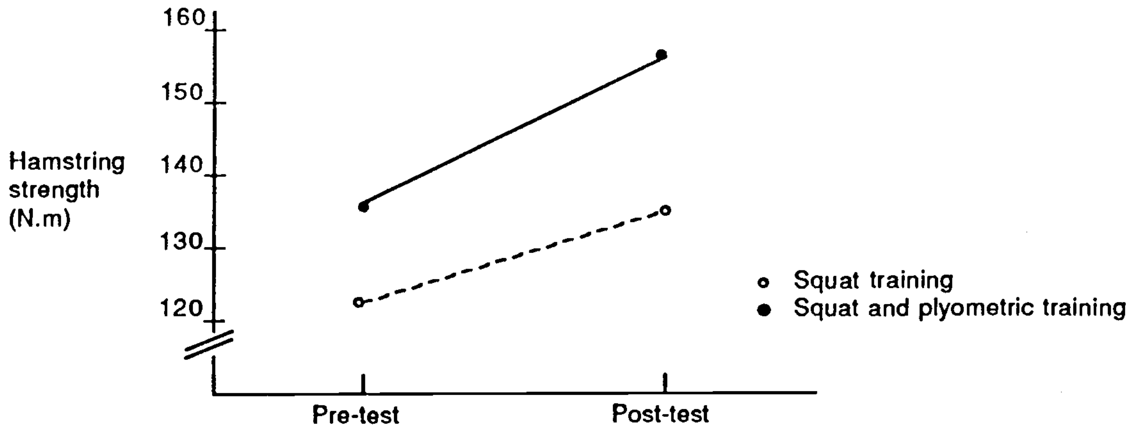
Hamstring strength changes with six weeks of squat, and combined squat and plyometric training.

Hamstring strength (N·m)	Squat			Squat/Plyometric		
	$\bar{X}$	SD	SE	$\bar{X}$	SD	SE
Pre-test	123.83	32.10	10.70	135.24	29.88	10.56
Post-test	136.03	37.12	12.37	157.61	24.96	8.82
Adjusted mean	140.26			152.87		
Difference mean	12.20			22.38		
Percentage change	9.85			16.55		
t	2.29			2.36		
P	.05*			.05*		

* Significant at the .05 level.

Figure 4.9

Hamstring strength pre-test and post-test mean scores



Relative Strength

The ratio of static leg strength to body weight was used to determine relative static strength. The ratio of quadricep and hamstring strength to body weight was used to measure relative dynamic strength.

Relative static strength

ANOVA was utilized to determine whether there were any significant differences in relative static strength between the squat training, and the combined squat and plyometric training. The results showed that the obtained *F* ratio (F = .82) was not significant at the .05 level (see Table 4.19), and the null hypothesis was accepted. That is, there was no significant difference between the two experimental groups in relative static strength, although overall averaged scores in relative static strength changed from the pre-test to the post-test state.

Table 4.20 shows that the two experimental groups decreased in relative static strength. The squat group pre-test level of relative static strength 11.84 N/kg decreased to a post-test level of 10.56 N/kg, a difference of 1.28 N/kg (10.81%). The combined squat and plyometric group also decreased with a .71 N/kg (6.24%) decrease from the pre-test mean to the post-test mean. The differences between the pre-test and post-test means for both groups were compared using the t-test. The computed t values for relative static strength of the squat group, and the combined squat and plyometric group were 3.21 and 1.41 respectively. The results showed significant differences at the .05 level in relative static strength for the squat group, while it did not decrease significantly in the combined squat and plyometric group. Figure 4.10 depicts changes in relative static strength from the pre-test mean to the post-test mean for the squat group.

Table 4.19

Repeated measures ANOVA for relative static strength.

Source of variation	df	SS	MS	F	P
Between groups	1	.265	.265	.06	.81
Within groups	15	66.396	4.426		
Between trials	1	8.346	8.346	9.85	.01*
Groups by trials	1	.691	.691	.82	.38
Within trials	15	12.715	.848		

* Significant at the .05 level.

Table 4.20

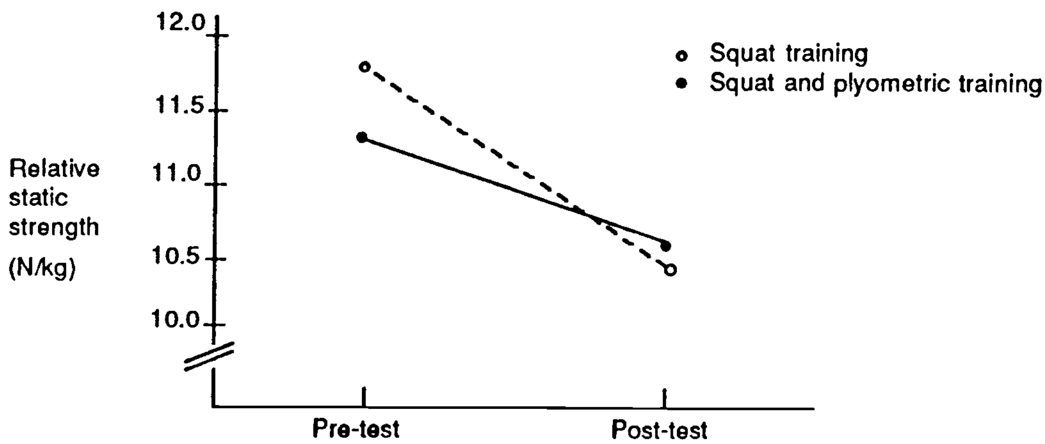
Relative static strength changes with 6 weeks of squat, and combined squat and plyometric training.

Relative static strength (N/kg)	Squat $\bar{X}$	Squat SD	Squat SE	Squat/Plyometric $\bar{X}$	Squat/Plyometric SD	Squat/Plyometric SE
Pre-test	11.84	1.85	.62	11.37	1.42	.50
Post-test	10.56	1.73	.58	10.67	1.40	.50
Adjusted mean	10.42			11.83		
Difference mean	1.28			.71		
Percentage change	10.81			6.24		
t	3.21			1.41		
P	.01*			.20		

* Significant at the .05 level.

Figure 4.10

Relative static strength pre-test and post-test mean scores.



Relative dynamic strength

A repeated measures ANOVA was conducted to determine whether there were any significant differences in relative dynamic strength between the squat training, and the combined squat and plyometric training. The results for the groups by trials showed that there was no significant difference between the two experimental groups in relative dynamic strength as measured by relative quadricep (F = 1.45) and relative hamstring strength (F = .70).

The differences between the pre-test and post-test means for both groups were compared using the t-test. The results showed no significant differences at the .05 level in relative dynamic strength for each group (see Table 4.22 and 4.24). Consequently, the null hypothesis was accepted. That is, each experimental group demonstrated nearly the same changes in relative dynamic strength by relative quadricep and relative hamstring strength from the pre-test mean to the post-test mean. Figures 4.11 and 4.12 show the relative dynamic strength pre-test means and post-test means for each group.

Table 4.21

Repeated measures ANOVA for relative quadricep strength.

Source of variation	df	SS	MS	F	P
Between groups	1	.025	.025	.04	.84
Within groups	15	8.602	.573		
Between trials	1	.038	.038	.35	.56
Groups by trials	1	.156	.156	1.45	.25
Within trials	15	1.615	.108		

Table 4.22

Relative quadricep strength changes with 6 weeks of squat, and combined squat and plyometric training.

Relative quadricep strength (N·m/kg)	Squat			Squat/Plyometric		
	$\bar{X}$	SD	SE	$\bar{X}$	SD	SE
Pre-test	3.42	.48	.16	3.34	.60	.21
Post-test	3.35	.48	.16	3.55	.75	.26
Adjusted mean	3.32			3.57		
Difference mean	.07			.20		
Percentage change	2.05			5.99		
t	.55			1.05		
P	.60			.33		

Figure 4.11

Relative quadricep strength pre-test and post-test mean scores.

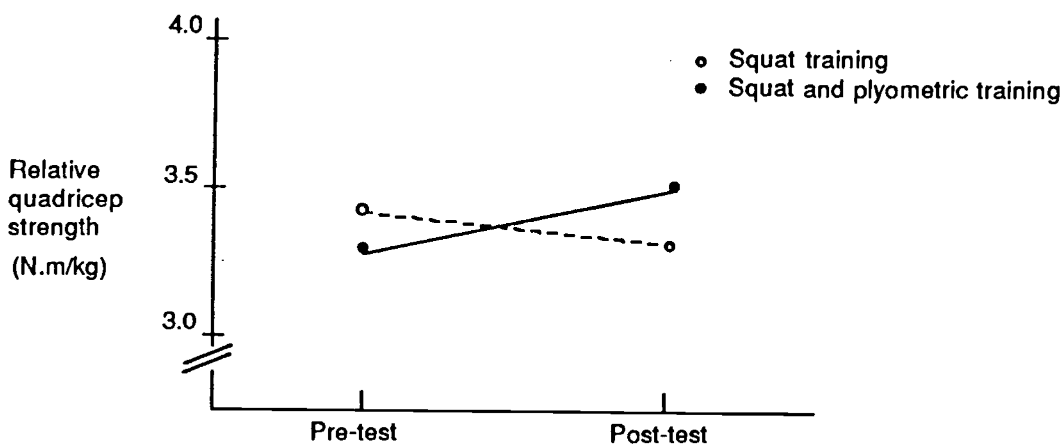


Table 4.23

Repeated measures ANOVA for relative hamstring strength.

Source of variation	df	SS	MS	F	P
Between groups	1	.065	.065	.46	.51
Within groups	15	2.097	.140		
Between trials	1	.296	.296	8.22	.01
Groups by trials	1	.025	.025	.70	.42
Within trials	15	.539	.036		

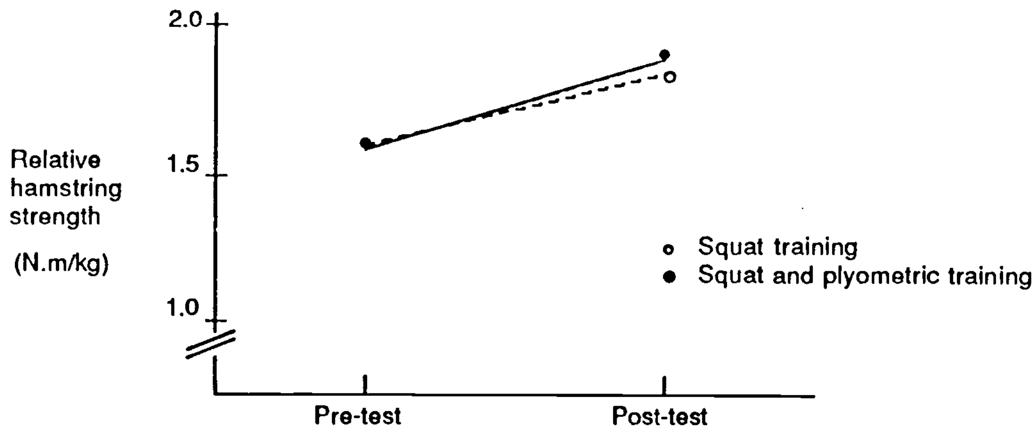
Table 4.24

Relative hamstring strength changes with 6 weeks of squat, and combined squat and plyometric training.

Relative hamstring strength (N·m/kg)	Squat			Squat/Plyometric		
	$\bar{X}$	SD	SE	$\bar{X}$	SD	SE
Pre-test	1.60	.31	.10	1.63	.28	.10
Post-test	1.73	.35	.12	1.87	.22	.08
Adjusted mean	1.74			1.86		
Difference mean	.13			.24		
Percentage change	8.13			14.72		
t	1.95			2.09		
P	.09			.08		

Figure 4.12

Relative hamstring strength pre-test and post-test mean scores.



Hamstring/Quadricep Ratio

ANOVA was applied to determine differences with respect to the hamstring/quadricep (H/Q) ratio change between the squat group, and the combined squat and plyometric group. Table 4.25 shows the test resulted in a computed F value of .17. This figure was not significant at the .05 level. The null hypothesis was accepted. There was no significant difference between the two experimental groups in H/Q ratio, although overall averaged scores in the H/Q ratio changed from pre-test to post-test levels.

The differences between the pre-test mean and the post-test mean for both groups were compared using a t-test. The results showed no significant difference at the .05 level in H/Q ratio for each group (see Table 4.26). Therefore, the null hypothesis was accepted. Each experimental group demonstrated nearly the same changes in H/Q ratio from the pre-test mean to the post-test mean. Figure 4.13 compares H/Q ratio pre-test means and post-test means for each group.

Table 4.25

Repeated measures ANOVA for hamstring/quadricep ratio.

Source of variation	df	SS	MS	F	P
Between groups	1	4.040	4.040	.16	.70
Within groups	15	386.076	25.738		
Between trials	1	18.038	18.038	4.97	.04*
Groups by trials	1	.615	.615	.17	.69
Within trials	15	54.492	3.632		

* Significant at the .05 level.

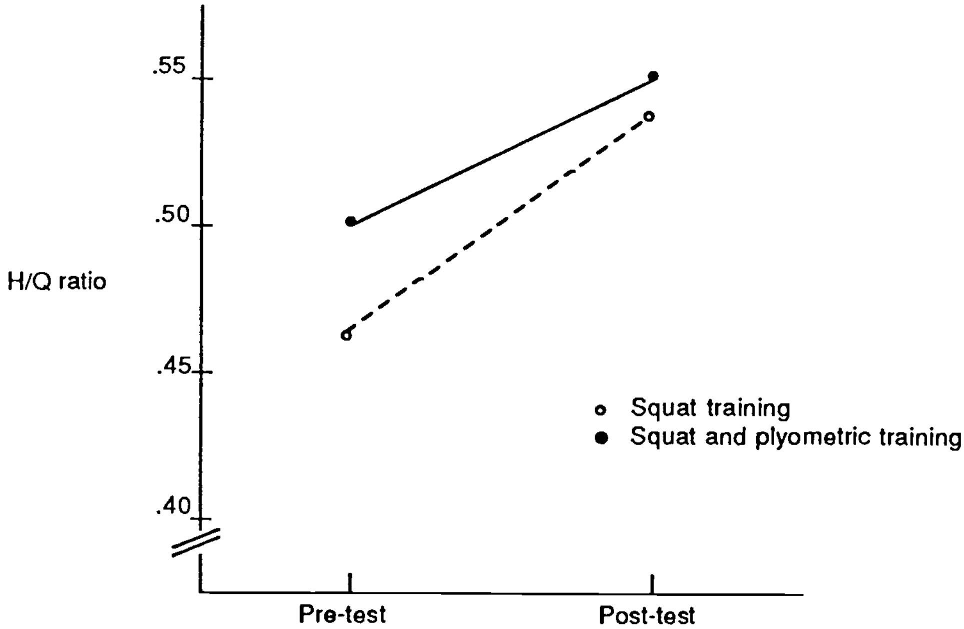
Table 4.26

Hamstring/quadricep ratio changes with 6 weeks of squat, and combined squat and plyometric training.

Hamstring/quadricep ratio	Squat			Squat/Plyometric		
	$\bar{X}$	SD	SE	$\bar{X}$	SD	SE
Pre-test	.47	.11	.04	.50	.14	.05
Post-test	.53	.14	.05	.54	.10	.04
Adjusted mean	.53			.52		
Difference mean	.05			.04		
Percentage change	10.64			8.00		
t	1.89			1.27		
P	.10			.24		

Figure 4.13

Hamstring/quadricep ratio pre-test and post-test mean scores.



Summary of Findings

The following points comprise a summary of the study (see Appendix F):

1. There was no significant difference at the .05 level between the squat group, and the combined squat and plyometric group in vertical power jump performance, quadricep and hamstring power, static leg strength, and dynamic leg strength.

2. There was a significant difference at the .05 level for vertical power jump performance within the combined squat and plyometric group, while it did not change significantly within the squat group.

3. There was no significant difference at the .05 level for quadricep power within squat group, and within the combined squat and plyometric group.

4. There was a significant difference at the .05 level for hamstring power within the squat, and within the combined squat and plyometric group.

5. There was a significant difference at the .05 level for static leg strength within the squat group. However, static leg strength did not change significantly within the combined squat and plyometric group.

6. There was no significant difference at the .05 level for quadricep strength within the squat group, and within the combined squat and plyometric group.

7. There was a significant difference at the .05 level for hamstring strength within the squat, and within the combined squat and plyometric group.

Discussion

Both the squat training group, and the combined squat and plyometric training group showed no significant changes in vertical power jump performance, static and dynamic leg strength, and muscular power. Therefore, no differences exist between the two training programs with respect to these variables. However, this study found a significant increase in vertical power jump performance based on pre-test and post-test mean scores within the combined squat and plyometric training group. This study also found significant improvements in hamstring strength and hamstring power when pre-test and post-test mean scores were compared. A significant decrease in static muscular strength also occurred in the squat training group.

Comparison of the Two Training Programs

The evidence generated by this study indicates that the vertical power jump performance, static and dynamic muscular strength, and muscular power are not significantly changed by six weeks of squat training, or by combined squat and plyometric training. There were no differences between the two training programs with respect to these variables.

In the present study it was expected that the combined squat and plyometric training program would result in an increase in the strength and power variables above that found by squat training alone. However, no significant differences occurred between the two training programs in this study. These results may be explained by the intensity and specificity of the exercises relative to strength and power production. The following are possible factors:

1. The same amount of intensity is achieved by heavier weight loads, low volume workouts (a few sets and repetitions), and longer recovery intervals.

2. The same specificity of dynamic strength training occurs in both training programs.

Another explanation for the insignificant differences in the strength and power variables may be due to the inadequate intensity duration and frequency required to stimulate the strength and power variable. American College of Sports Medicine (1986) made recommendations for the quality and quantity of exercise needed for muscle strength maintenance and enhancement. Muscular strength is acquired either by dynamic high-tension low-repetitions exercise or static contraction training. General strength training programs should be performed three times per week with three sets of five to seven repetitions. This, however, is not recommended by the National Strength and Conditioning Association for athletic training. The Association suggests that the training programs should be executed four times per week following a split routine (Pauletto, 1985, 1986).

The subjects in this study had nearly the same physical characteristics and had closely related strength and power. Since the subject were part of the advanced weight training class, they were already cognizant of weightlifting skills. This knowledge might contribute to their similar performance. The subjects' similarity in physical characteristics and weightlifting experience may explain the lack of statistical significance in this study.

Increase in Vertical Power Jump Performance

The combined squat and plyometric training program resulted in a significant increase in power, as measured by the subject's vertical power jump ability. This finding is consistent with the findings of other investigators (Brown et al., 1986; Miller, 1982; Verkhoshanski & Tatyan, 1983). They found significant changes in speed-strength and jump performance through plyometric training. When both weight training and plyometric training are used researchers have confirmed that there are significant effects on the development of strength and jump performance (Blakey, 1985; Blattner & Noble, 1979; Bosco et al., 1982; Clutch et al., 1983; Polhemus & Burkhardt, 1980).

<u>Increase in Dynamic Muscular Strength</u>

One of the study's findings was an increase in hamstring dynamic strength within the squat training group (12.20 N·m), and within the combined squat and plyometric training group (22.38 N·m). The squat training group increased 9.85% in hamstring strength and the combined squat and plyometric group increased 16.55%. The hamstring muscle group is smaller and weaker than the quadricep muscle group so hamstrings can develop strength at a relatively more rapid rate than the quadriceps. This study also showed no statistically significant increase in quadricep dynamic strength within the two training programs. The quadriceps are initially stronger relative to their capacity for development than hamstrings, therefore increases in quadricep strength are more difficult (Fry & Powell, 1987; Kisner & Colby, 1985). This finding was expected since previous studies involving squat and plyometric training have shown similar results in dynamic muscular strength development (Blakey, 1985; Clutch et al., 1983; O'Shea & Wegner, 1981).

Changes in neuromuscular function and neuromuscular adaptation (O'Shea, 1979, 1985b; Stone, 1982; Yessis, 1981) may explain the fact that dynamic muscular strength increased with both training groups. Overloading through progressive resistance exercise on skeletal muscle results in strength development (Berger, 1962a, 1962c, 1962d; DeLorme & Watkins, 1948; O'Shea, 1979).

<u>Increase in Muscular Power</u>

Following the 6-week training program of squat, and combined squat and plyometric exercise, significant increases were observed in the hamstring power (6.39 W and 11.71 W respectively) for both training groups. The squat training gained 9.86% in hamstring power, and the combined squat and plyometric training groups increased 16.51% from the pre-test levels. No statistically significant increases occurred in quadricep power within the two training programs. In the present study, it was expected that both training programs would result in an increase in hamstring power. Since muscular power can be considered as muscular strength multiplied by limb velocity, the increase in power for both training groups can account for the increase in hamstring strength and/or the increase in limb velocity. No tests were conducted in this study to measure increase in limb velocity. However, both training groups resulted in a significant increase in hamstring strength, as measured by the Cybex II isokinetic dynamometer. Therefore, the increase in hamstring power for both groups is at least partially due to the increase in hamstring strength. The increase in power can be explained by the fact that both training programs involved squat movement. According to O'Shea (1979, 1985a) and Wathen & Shutes (1982), the squat exercises lead to the best development of strength and power.

Decrease in Static Muscular Strength

Significant losses occurred in static muscular strength from pre-test levels for the squat group (900.02 N and 807.11 N). The combined squat and plyometric group also declined in static muscular strength values (935.79 N and 895.48 N). The decrease in static muscular strength within the squat group was 10.32%, and the decrease in the combined squat and plyometric group was 4.31%. This finding supports the findings of Berger (1962b), who found that dynamic strength training improved dynamic strength more than static strength training. There was no significant relationship between improvement in static and dynamic strength. Both training programs are dynamic strength training types which use a full range of joint motion, and eccentric and concentric contraction. Therefore these training programs do not have a positive effect on static strength This result is due to specificity training. However, these findings are contrary to the research findings of Clutch et al. (1983), where the authors used weight training and three different jumping exercises. In that study the exercises resulted in increased isometric knee extension strength (static strength).

CHAPTER 5

CONCLUSIONS

Summary

The purpose of this study was to determine the relative effectiveness of a 6-week strength training program comprised of squat and combined squat and plyometric training on vertical power jump performance, static and dynamic muscular strength, and muscular power production.

A literature review established that a number of studies have been published in the area of free weight training in squat, bench press and dumbells, etc. for strength development, and plyometric training for power jump performance. However, no studies were found that tested the effect of squat training, and combined squat and plyometric training on the development of both static and dynamic muscular strength and muscular power production.

This experiment was conducted during the winter term of the 1988 academic year. All training was done in the weight training room at Langton Hall within the Department of Physical Education at Oregon State University, Corvallis, Oregon. The subjects consisted of 15 male students and two female students who had registered in the advanced weight training class.

A pre-test and post-test randomized groups design was employed for this study. The subjects were first paired and then randomly assigned to either the squat group or the combined squat and plyometric group based on the muscular strength and power of the subjects in the pre-test. The training sessions were limited to 50 minutes twice a week over six weeks.

All subjects were tested for vertical power jump performance, static muscular strength, dynamic muscular strength and muscular power prior to the 6-week training period. The subjects were retested following the 6-week period. All testing was done in the Exercise Science Instructional Laboratory at Langton Hall within the Department of Physical Education at Oregon State University. A vertical power jump test was used as the power criterion. A cable tensiometer was utilized as the static muscular strength test. A Cybex II dynamometer served to test dynamic muscular strength, and muscular power with respect to the quadriceps and hamstrings.

For each dependent variable the relative amount of change was determined in each group from the pre-test and post-test levels. Initial and final means within each group were analyzed by a "t" test. Repeated measures analysis of variance was used to assess significant differences between the two group mean scores. A .05 level of significance was used as the critical level for rejection of the null hypotheses in the study.

In terms of results, the following findings are reported:

1. There were no significant differences between the two training programs in vertical power jump performance, quadricep and hamstring strength and power, and static muscular leg strength.

2. There was a significant difference in the pre-test and post-test means for the vertical power jump within the combined squat and plyometric group.

There was no significant difference between the pre-test and post-test means for vertical power jump performance within the squat group.

3. There was no significant difference in the pre-test and post-test means for quadricep strength and power within the squat group, and within the combined squat and plyometric group.

4. There was a significant difference in the pre-test and post-test means for hamstring strength and power within the squat group, and within the combined squat and plyometric group.

5. There was a significant difference in the pre-test and post-test means for static muscular leg strength within the squat group.

There was no significant difference in the pre-test and post-test means for static muscular leg strength within the combined squat and plyometric groups.

Conclusions

In considering the procedural limitations which occurred in this study, the following conclusions seem justified:

1. Six weeks of training in squat, and combined squat and plyometric exercise produce significant increases in vertical power jump performance, in dynamic muscular strength and in muscular power based on pre-test and post-test means.

2. After six weeks of training with squat exercises pre-test and post-test means significantly decreased. This reflects a decline in static leg strength.

3. A six weeks program of squat, and combined squat and plyometric training does not produce a statistically significant difference in muscular strength and muscular power.

Recommendations

Further investigations are indicated based on the results of this study. The following recommendations can be made.

1. The effect of training duration and the number of workouts should be investigated with respect to squat and combined squat and plyometric training:

1.1 The effect of three or more workouts per week should be researched utilizing a split training program.

1.2 Research with an 8-week or greater training period should be conducted.

2. A study similar to the present study should be undertaken with a larger sample size representing various age groups and an increased female sample group.

3. A comparative study similar to the present study is suggested, consisting of subjects in a control group and/or plyometric group.

4. A study is needed to investigate the effect of reversing the order of the training programs, that is, plyometric training followed by squat training in the combined training group.

5. Research is necessary to examine the effects of combined upper body weight training and plyometric programs on power production.

6. Finally, investigation is suggested to observe relationships between limb lengths and muscular power production.

Applications

The results of this study will assist physical educators and coaches in designing more effective training programs both at the high school and college level. Since combined squat and plyometric exercise produces significant increases in muscular power, particularly for leg muscles, the exercises can be applied in a general conditioning program.

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APPENDICES

Appendix A

TRAINING OUTLINE

<u>6-week Squat Training Program</u>

1. <u>Conditioning Phase</u>
   (Week 1-2)

	Intensity	Set		Reps
Warm up	5 minutes of stationary cycling			
Progression warm up squat	135 lbs	1	x	10
	185 lbs	1	x	5
	205 lbs	1	x	5
Squat treatment	70% of capacity	3	x	8-10
Cool down	5 minutes of upper body exercise			

2. <u>Strength Phase</u>
   (Week 3-4)

	Intensity	Set		Reps
Warm up	5 minutes of stationary cycling			
Progression warm up squat	135 lbs	1	x	10
	185 lbs	1	x	5
	205 lbs	1	x	5
Squat treatment	80% 1-RM	3	x	5
Cool down	5 minutes of upper body exercise			

3. <u>Power Phase</u>
   (Week 5-6)

	Intensity	Set		Reps
Warm up	5 minutes of stationary cycling			
Progression warm up squat	135 lbs	1	x	10
	185 lbs	1	x	5
	205 lbs	1	x	5
	225 lbs	1	x	2
Squat treatment	90% 1-RM (heavy day)	3	x	3
Squat treatment	80% 1-RM (light day)	3	x	3
Cool down	5 minutes of upper body exercise			

6-week Combined Squat and Plyometric Training Program

1. Conditioning Phase*
(Week 1-2)

	Intensity	Set		Reps
Squat treatment	70% of capacity	2	x	10
5 minutes of rest				
Plyometric treatment	Depth jumps (.71m)	2	x	5
	Box jumps (.71m)	2	x	5
1 minute of rest between each set				

2. Strength Phase*
(Week 3-4)

	Intensity	Set		Reps
Squat treatment	80% 1-RM	2	x	5
3 minutes of rest				
Plyometric treatment	Depth jumps (.71m)	3	x	5
	Box jumps (.71m)	3	x	5
1 minute of rest between each set				

3. Power Phase*
(Week 5-6)

	Intensity	Set		Reps
Squat treatment	90% 1-RM (heavy day)	2	x	2
	80% 1-RM (light day)	2	x	2
3 minutes of rest				
Plyometric treatment	Depth jumps (.71m)	3	x	7
	Box jumps (.71m)	3	x	7
1 minute of rest between each set				

* The warm up, progression warm up squat and cool down are identical to the squat training program.

Appendix B

SUBJECTS INFORMED CONSENT

Strength research study, Winter term 1988

Principal investigator: Pat O'Shea, professor

Assistant investigator: Thanomwong Taweeboon Kritpet

The primary purpose of this study is to determine the effects of a 6-week training program of squat and plyometrics on power production.

To make this determination a 6-week experimental training has been established. The experimental protocol will be as follows:

1. Prior to the start of the experimental period there will be a 2-week training and conditioning program during which time each subject will learn and practice the techniques of squatting and plyometrics.

2. Following the pre-experimental period there will be pre-testing to evaluate strength and power. The methods used as testing indices are:

- Dynamic leg strength and leg power. Assessed by a Cybex II isokinetic strength and power test.

- Static leg strength. Measured by a static cable tensiometer test.

- Leg power. Measured by a vertical power jump test.

3. At the completion of the pre-testing period, the 6-week experimental training period will begin. For the duration of the training period the subjects will be randomly assigned to one of two groups: a squat group and a combined squat and plyometric group. The two groups will follow specific training protocol utilizing the

progressive overload exercise with respect to the load, intensity, and volume of training. Training intensity will vary from 70% to 90% of each subject's pre-test squat 1-RM. Training sessions will be Tuesday and Friday and last 50 minutes.

4. Post-test evaluation will take place at the conclusion of the 6-week experimental training period.

Risks and/or Benefits

The risks of injury to the subjects participating in this study are no greater than to students enrolled in an intermediate circuit training activity class. During all training sessions safety precautions will be strictly followed. These include: (a) the use of two or more spotters at all times, (b) the wearing of lifting belts and knee wraps during all testing sessions, (c) the use of correct lifting techniques at all times, (d) the use of correct depth jump and box jump techniques at all times.

The benefits to be derived from participating in the study are: (a) development of a high degree of strength and power, (b) knowledge of advanced strength and power training techniques, (c) an elementary knowledge of exercise physiology relating to strength development.

All training sessions will be closely supervised by Dr. O'Shea and any injuries that may occur will receive his immediate attention.

Participation in this study is voluntary and the student may withdraw at any time without penalty.

Anonymity. Each subject will be assigned a number under which all test results will be recorded. At no time will a subject's name be used. All test results are confidential.

Appendix C

INFORMED CONSENT RELEASE

In consideration of the benefits to be derived and the data to be generated, the undersigned, a student of Oregon State University, agrees to participate in the research project, "The Effects of Six Weeks of Squat and Plyometric Training on Power Production." The undersigned states that he or she has read an outline of the proposed study, including the possible risks and benefits, and is participating voluntarily. The subject consents to follow the testing and training program as outlined. The undersigned also agrees to the use of the data generated as the above agencies may desire. At any time during the study, if circumstances should arise and the undersigned cannot complete the study, he or she is free to discontinue.

____
Participant

____
Date

Appendix D

AGE AND PHYSICAL CHARACTERISTICS OF THE SUBJECTS

The Squat Group

Subject	Sex	Age	Height (cm)	Body Weight (kg)
1	M	21	189	77
2	M	22	175	63
3	M	20	181	84
4	M	20	170	72
5	M	23	180.5	90.5
6	M	23	168.5	75
7	F	19	158.5	59.5
8	M	21	186	95.5
9	M	21	176	75.5
$\bar{X} \pm$ SD		21.11 ± 1.36	176.06 ± 9.45	76.89 ± 11.76

The Combined Squat and Plyometric Group

Subject	Sex	Age	Height (cm)	Body Weight (kg)
1	M	19	177.5	101
2	M	21	177	80
3	M	19	174.5	72.5
4	F	26	175.5	68
5	M	34	182	84
6	M	19	181	75
7	M	26	189.5	96
8	M	25	180	86
$\bar{X} \pm$ SD		23.63 ± 5.24	179.63 ± 4.78	82.81 ± 11.41

APPENDIX E

RAW DATA FOR THE TWO TRAINING PROGRAMS

The Squat Group

Subject	Test	Body Weight (kg)	Jump Height (cm)	Jump Time (sec)	Vertical Power Jump (kg.m/sec)	Quadricep Power (W)	Hamstring Power (W)	Static Strength (N)	Quadricep Strength (N·m)	Hamstring Strength (N·m)	Relative Static Strength (N/kg)	Relative Quadricep Strength (N·m/kg)	Relative Hamstring Strength (N·m/kg)	H/Q Strength Ratio
1	Pre	77	50	.5880	130.952	127.781	59.631	790.491	244.047	113.889	9.214	3.169	1.479	.467
	Post	80	56	.6110	146.645	161.856	59.631	769.542	309.127	113.889	9.619	3.864	1.424	.368
2	Pre	63	49	.6570	93.973	127.781	34.075	834.042	244.047	65.079	13.239	3.874	1.033	.267
	Post	65	65.5	.7015	121.383	127.781	34.075	738.405	244.047	65.079	11.360	3.755	1.001	.267
3	Pre	84	58.5	.6335	155.138	157.596	74.539	1052.005	300.992	142.361	12.524	3.583	1.695	.473
	Post	85	62	.6120	172.222	144.818	93.706	889.644	276.587	178.968	10.466	3.254	2.106	.647
4	Pre	72	63	.6330	143.318	106.484	68.150	834.042	203.373	130.159	11.584	2.825	1.808	.640
	Post	72	58	.6230	134.061	115.003	76.668	769.542	219.643	146.428	10.688	3.051	2.034	.667
5	Pre	90.5	41	.5280	140.549	153.337	78.798	954.144	292.857	150.496	10.543	3.236	1.663	.514
	Post	93	40.5	.5450	138.220	125.651	80.928	842.938	239.980	154.563	9.064	2.580	1.662	.644
6	Pre	75	53	.6325	125.692	170.374	76.668	1134.297	325.396	146.428	15.124	4.339	1.952	.450
	Post	76	62.5	.6560	144.817	163.985	76.668	923.006	313.194	146.428	12.145	4.121	1.927	.468
7	Pre	59.5	38.5	.5095	89.921	89.446	40.464	738.405	170.833	77.282	12.410	2.871	1.299	.452
	Post	59	38.5	.5605	81.053	91.576	51.112	753.974	174.901	97.619	12.779	2.964	1.655	.558
8	Pre	95.5	49	.5865	159.574	178.893	72.409	918.558	341.666	138.293	9.618	3.578	1.448	.405
	Post	96.5	51.5	.5995	165.796	170.374	91.576	693.923	325.396	174.901	7.191	3.372	1.812	.538
9	Pre	75.5	48.5	.5770	126.924	132.040	78.798	925.230	252.182	150.496	12.255	3.340	1.993	.597
	Post	75.5	67	.6645	152.250	127.781	76.668	882.972	244.047	146.428	11.695	3.232	1.939	.600

The Combined Squat and Plyometric Group

Subject	Test	Body Weight (kg)	Jump Height (cm)	Jump Time (sec)	Vertical Power Jump (kg.m/sec)	Quadricep Power (W)	Hamstring Power (W)	Static Strength (N)	Quadricep Strength (N·m)	Hamstring Strength (N·m)	Relative Static Strength (N/kg)	Relative Quadricep Strength (N·m/kg)	Relative Hamstring Strength (N·m/kg)	H/Q Strength Ratio
1	Pre	101	51	.6165	167.105	204.449	76.668	1067.573	390.476	146.428	10.570	3.866	1.450	.375
	Post	100	52	.5370	193.669	174.156	85.187	1005.298	332.619	162.698	10.053	3.326	1.627	.482
2	Pre	80	55.5	.6295	141.064	108.614	76.668	1005.298	207.440	146.428	12.566	2.593	1.830	.706
	Post	80.5	58	.6265	149.050	149.078	93.706	1020.867	284.722	178.968	12.682	3.537	2.223	.629
3	Pre	72.5	58	.6310	133.281	157.596	48.982	976.385	300.992	93.551	13.467	4.152	1.290	.311
	Post	76.5	54	.6230	132.616	195.931	76.668	931.903	374.206	146.428	12.182	4.892	1.914	.391
4	Pre	68	41	.4810	115.925	106.484	51.112	680.578	203.373	97.619	10.008	2.991	1.436	.480
	Post	72	42	.4905	123.303	110.743	59.631	791.784	211.508	113.889	10.997	2.938	1.582	.538
5	Pre	84	50	.5970	140.704	129.911	59.631	834.042	248.115	113.889	9.929	2.954	1.356	.459
	Post	85	54.5	.5855	158.241	140.559	89.446	738.405	268.452	170.833	8.687	3.158	2.010	.636
6	Pre	75	59	.6465	136.891	161.856	76.668	976.385	309.127	146.428	13.018	4.122	1.952	.474
	Post	79	63.5	.6690	149.970	176.763	76.668	785.111	337.599	146.428	9.938	4.273	1.854	.434
7	Pre	96	59	.5820	194.639	153.337	87.317	998.626	292.857	166.766	10.402	3.051	1.737	.569
	Post	95	72	.5945	230.109	183.152	102.225	1089.814	349.801	195.238	11.472	3.682	2.055	.558
8	Pre	86	49.5	.5620	151.495	135.589	89.446	947.471	258.961	170.833	11.017	3.011	1.986	.660
	Post	86	59.5	.6715	152.405	115.003	76.668	800.680	219.643	146.428	9.310	2.554	1.703	.667

Appendix F

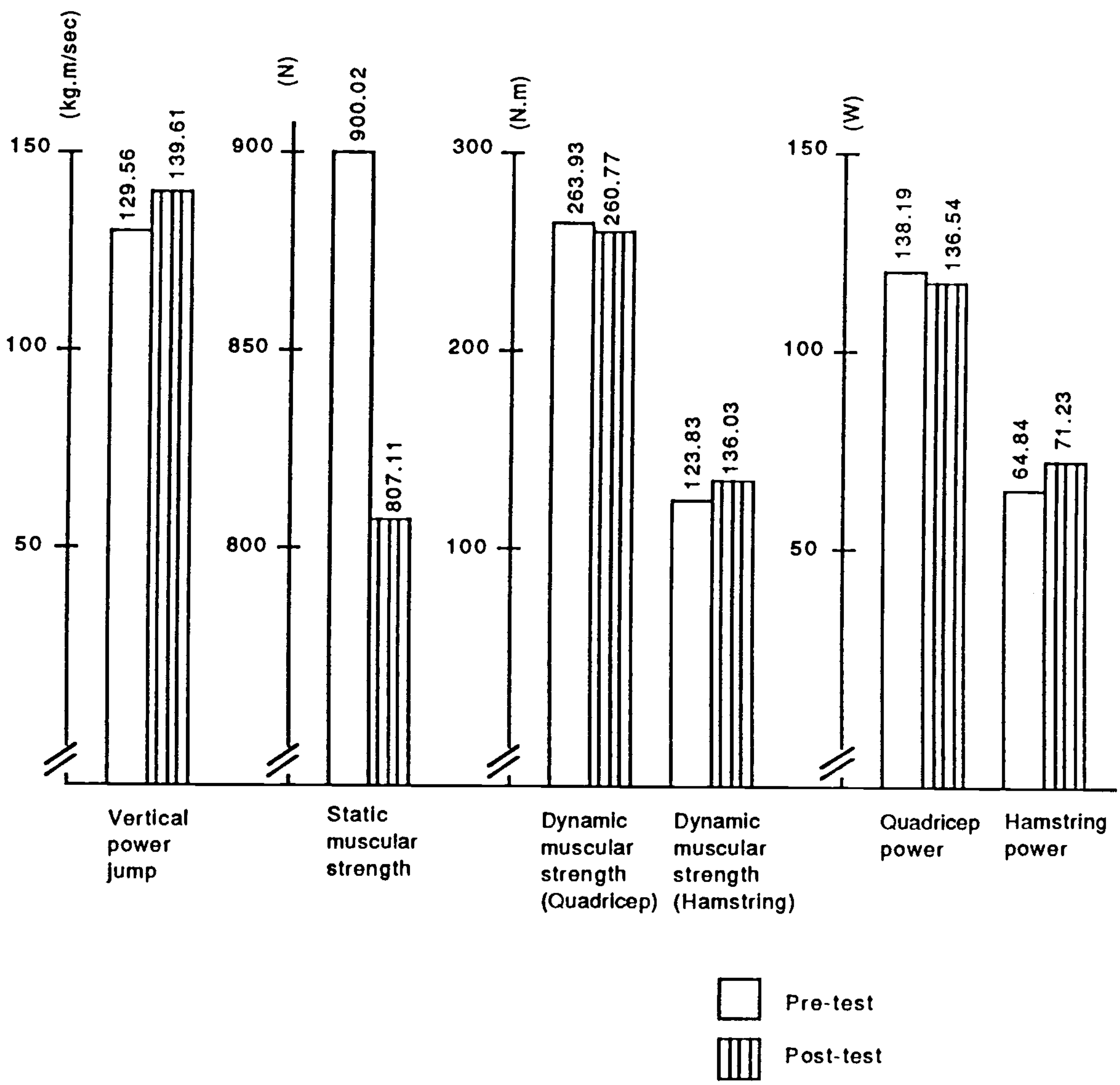
SUMMARY OF RESULTS FROM PRE-TEST AND POST-TEST MEAN SCORES

Tests	Training Program	Pre-test $\bar{X}$	Pre-test SD	Post-test $\bar{X}$	Post-test SD	t	% change
Vertical Power Jump (kgm/sec)	Squat	129.56	24.31	139.61	26.88	2.13	7.76
	Squat/Plyometric	147.64	23.97	161.17	34.67	3.06*	9.16
Static Leg Strength (N)	Squat	900.02	138.30	807.11	79.42	-2.88*	-10.32
	Squat/Plyometric	935.79	122.51	895.48	132.81	-1.06	-4.31
Quadricep Strength (N·m)	Squat	263.93	56.23	260.77	49.46	-0.29	-1.20
	Squat/Plyometric	276.42	61.12	279.32	60.86	1.19	7.56
Hamstring Strength (N·m)	Squat	123.83	32.10	136.03	37.12	2.29*	9.85
	Squat/Plyometric	135.24	29.88	157.61	24.96	2.36*	16.55
Quadricep Power (W)	Squat	138.19	29.44	136.54	25.90	-0.29	-1.20
	Squat/Plyometric	144.73	32.00	155.67	31.86	1.19	7.56
Hamstring Power (W)	Squat	64.84	16.81	71.23	19.44	2.29*	9.86
	Squat/Plyometric	70.81	15.64	82.52	13.07	2.36*	16.54

* $P < .05$

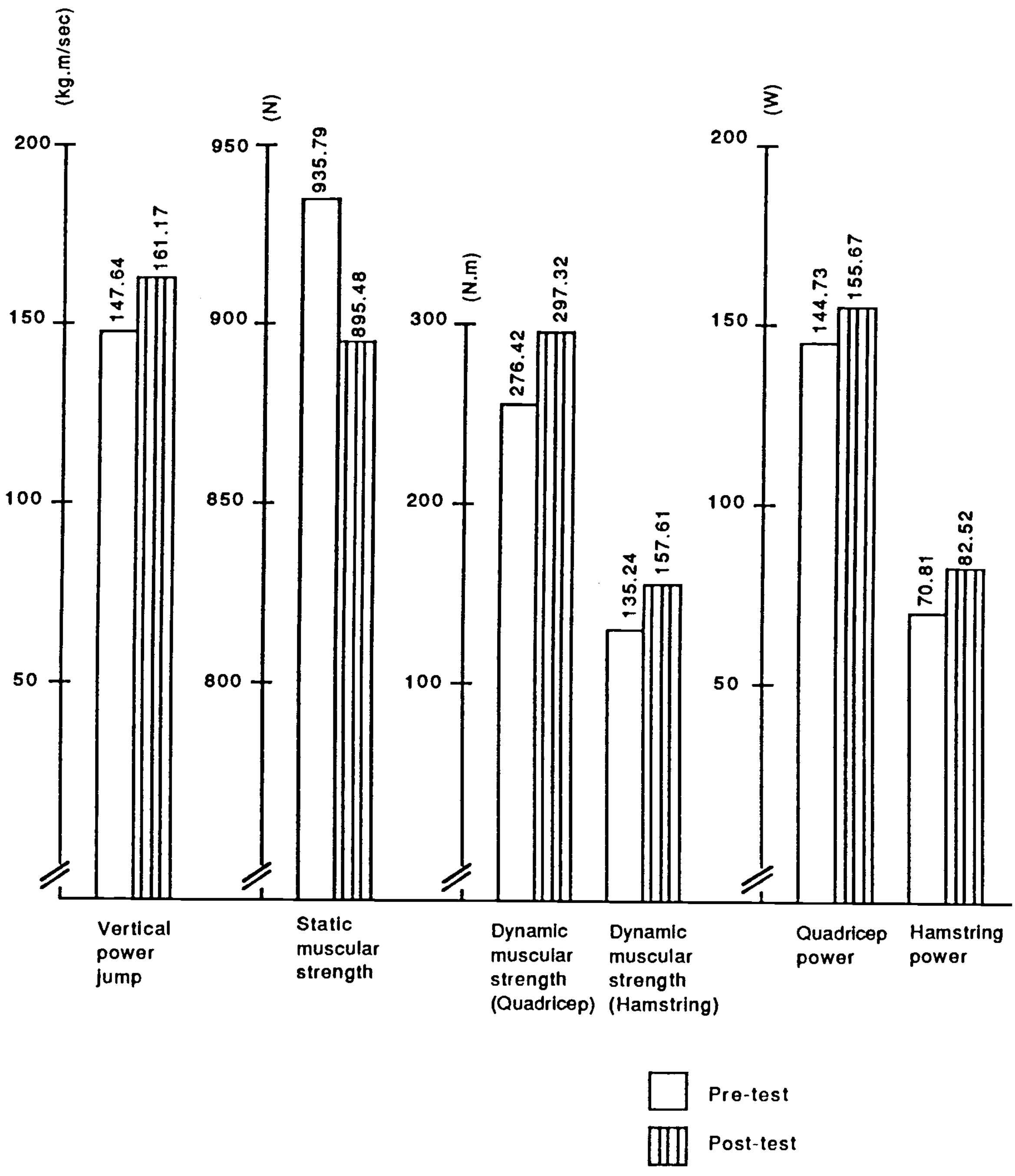
Appendix F -- continued

Changes in Vertical Power Jump Performance, Static and Dynamic Muscular Strength, and Muscular Power within the Squat Training Group.



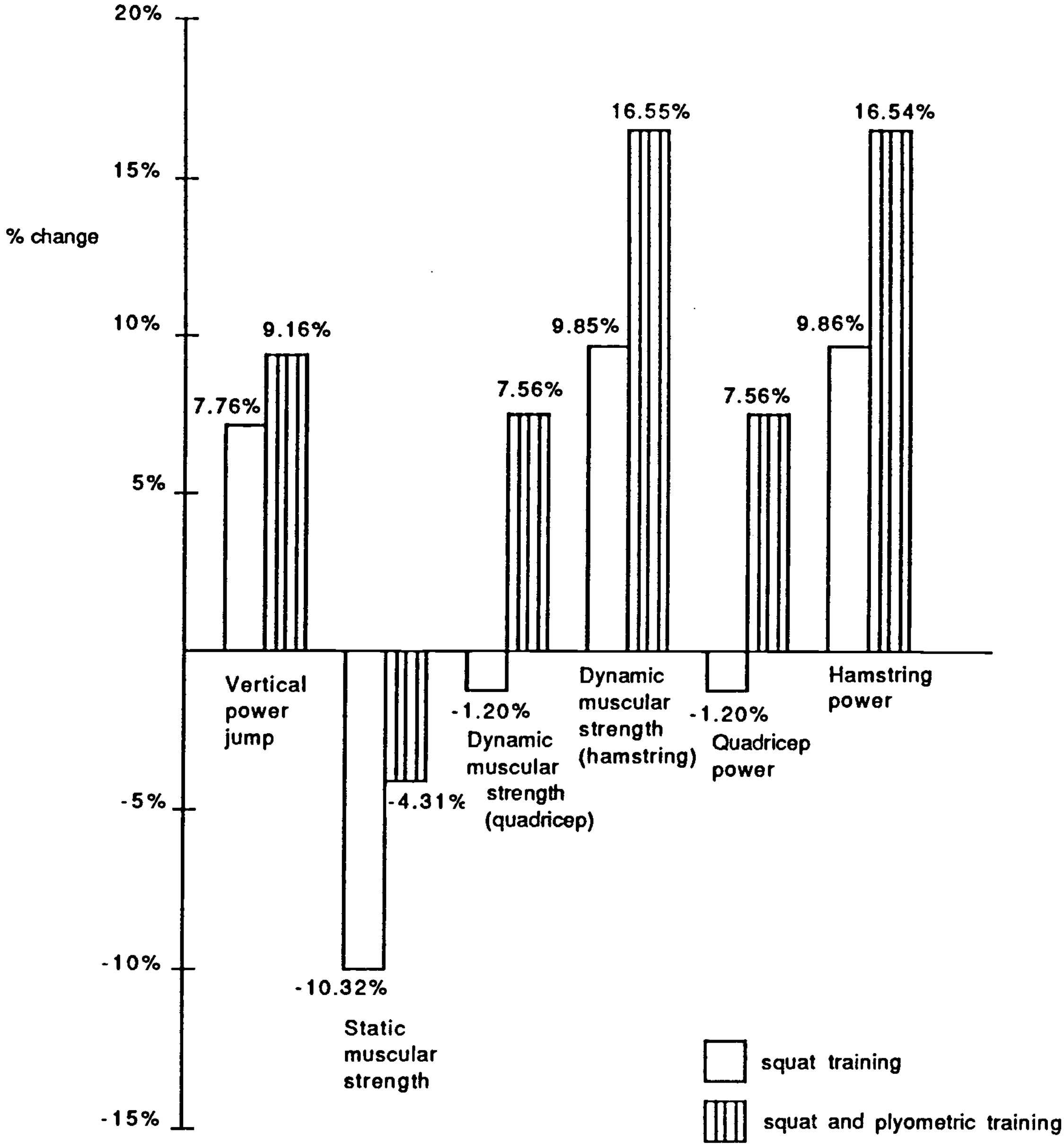
Appendix F -- continued

Changes in Vertical Power Jump Performance, Static and Dynamic Muscular Strength, and Muscular Power within the Combined Squat and Plyometric Training Group.



Appendix F -- continued

Changes in Vertical Power Jump Performance, Static and Dynamic Muscular Strength, and Muscular Power.



Appendix G

SQUAT AND PLYOMETRIC EXERCISES

Squat Exercise

Figure G.1. Front view of the squat position.

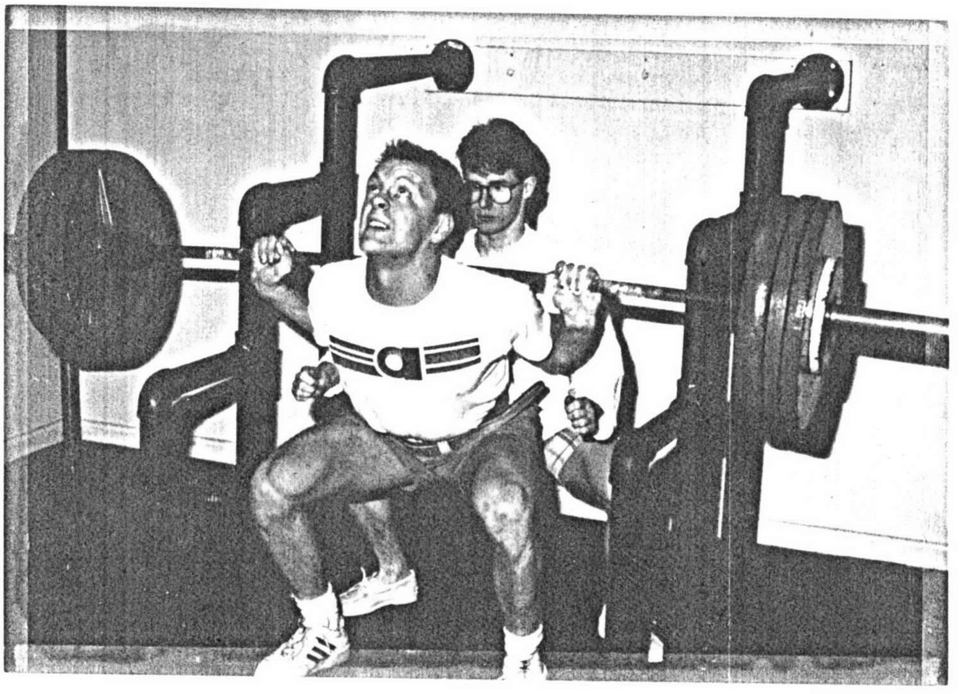
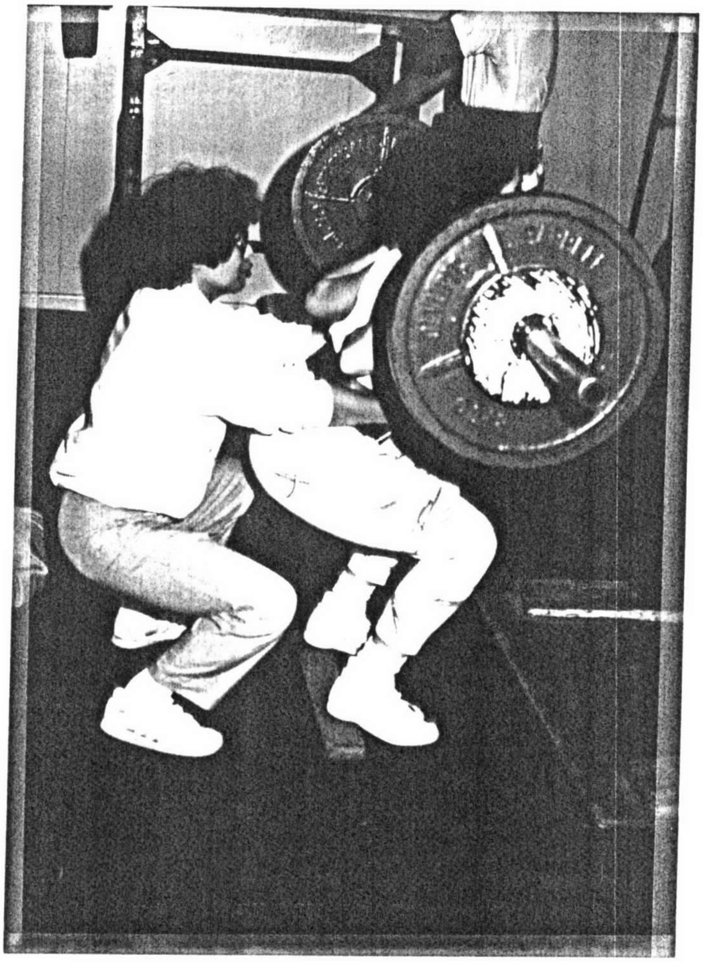


Figure G.2. Rear view of the squat position.



Plyometric Exercise

Figure G.3. Start position.

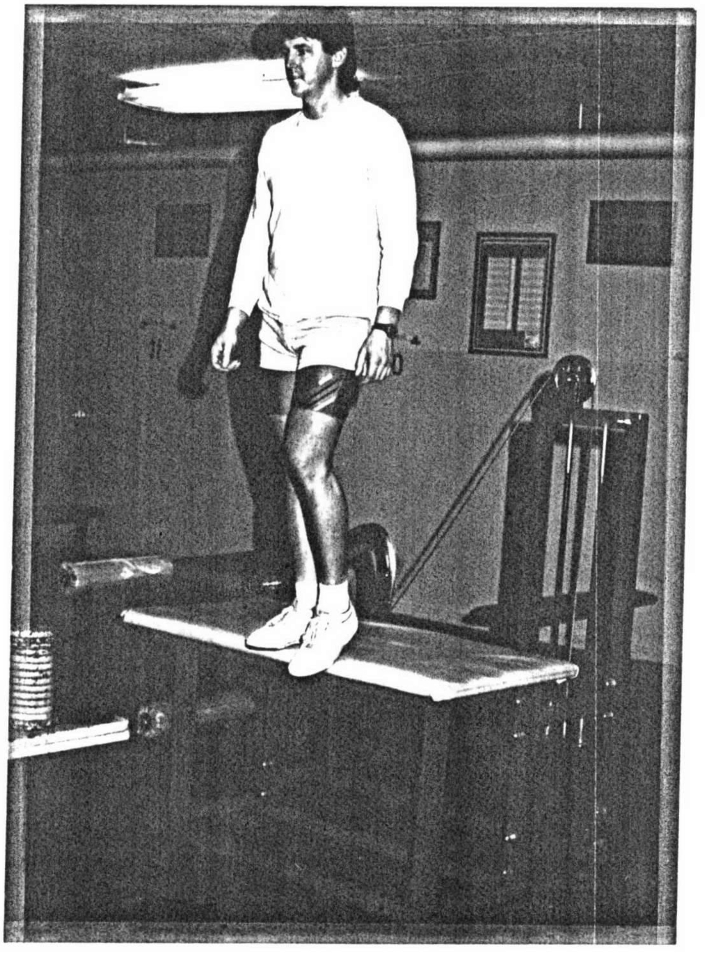


Figure G.4. Landing position.

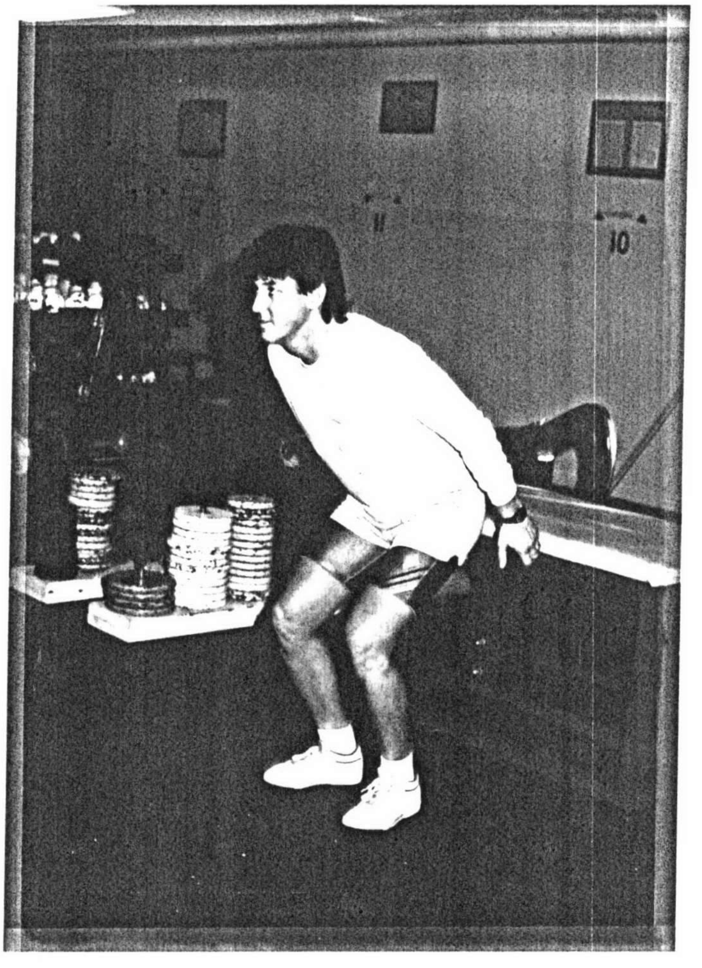


Figure G.5. Immediate rebound.

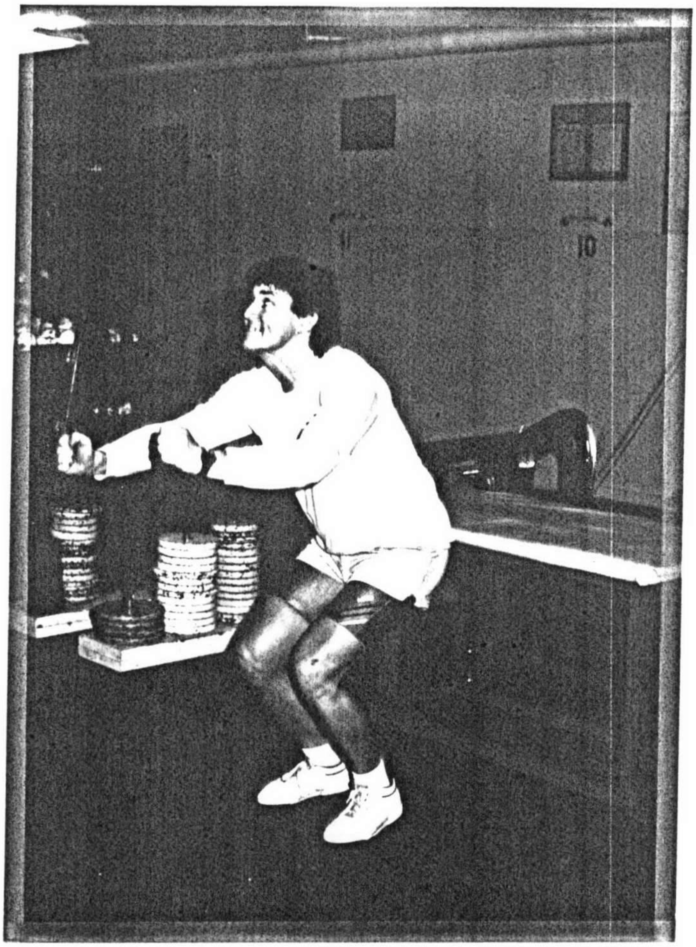
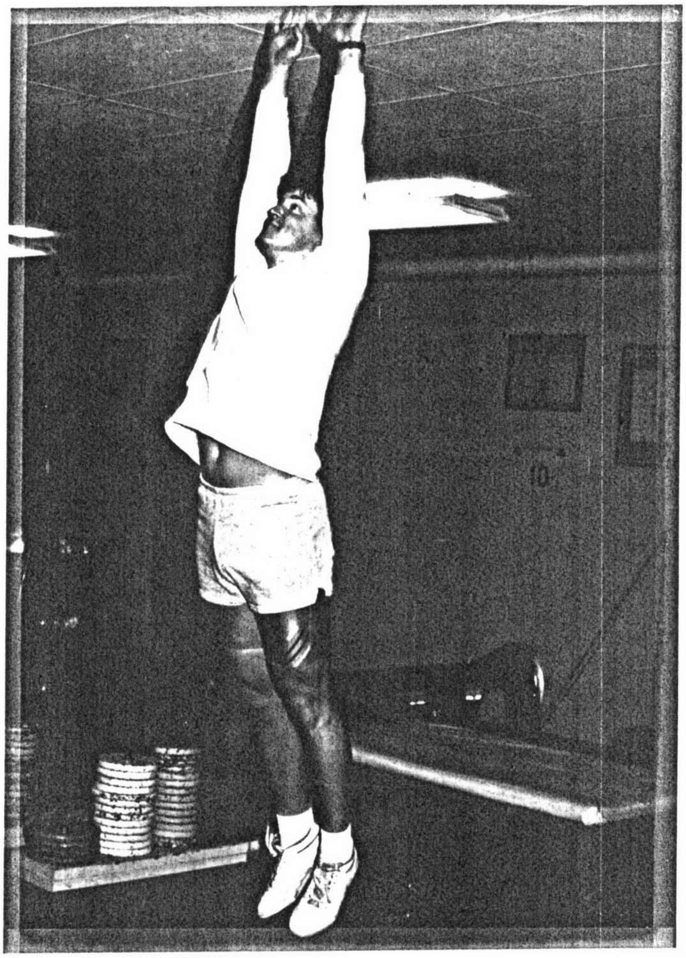


Figure G.6. Vertical upward jump.



Appendix H

TESTING PROCEDURE

Figure H.1. Vertical power jump test.

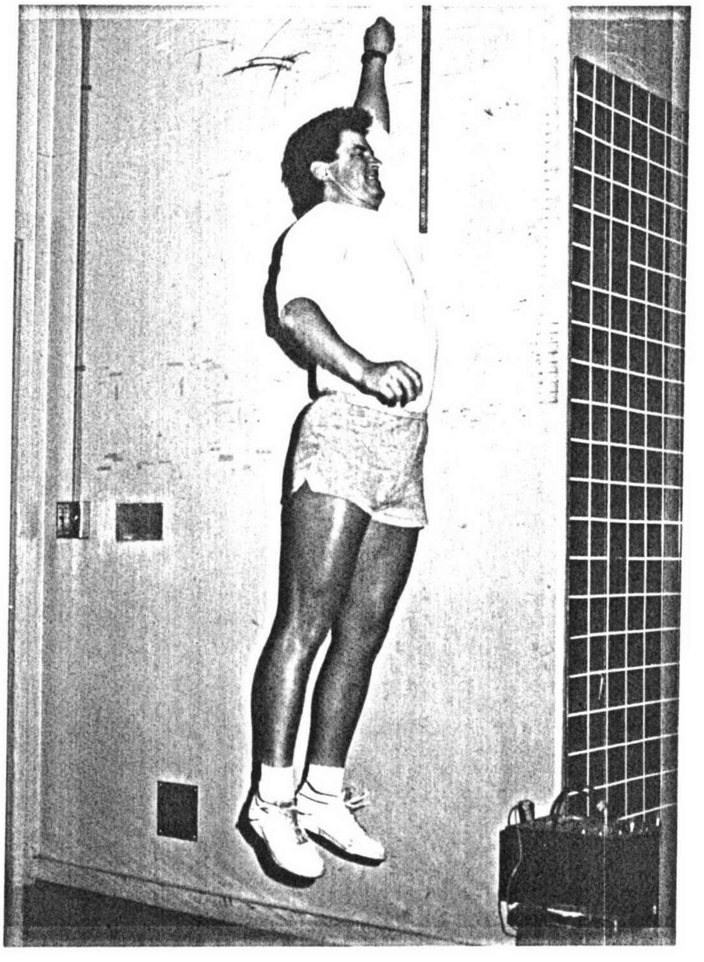


Figure H.2. Static leg strength test with a cable tensiometer.

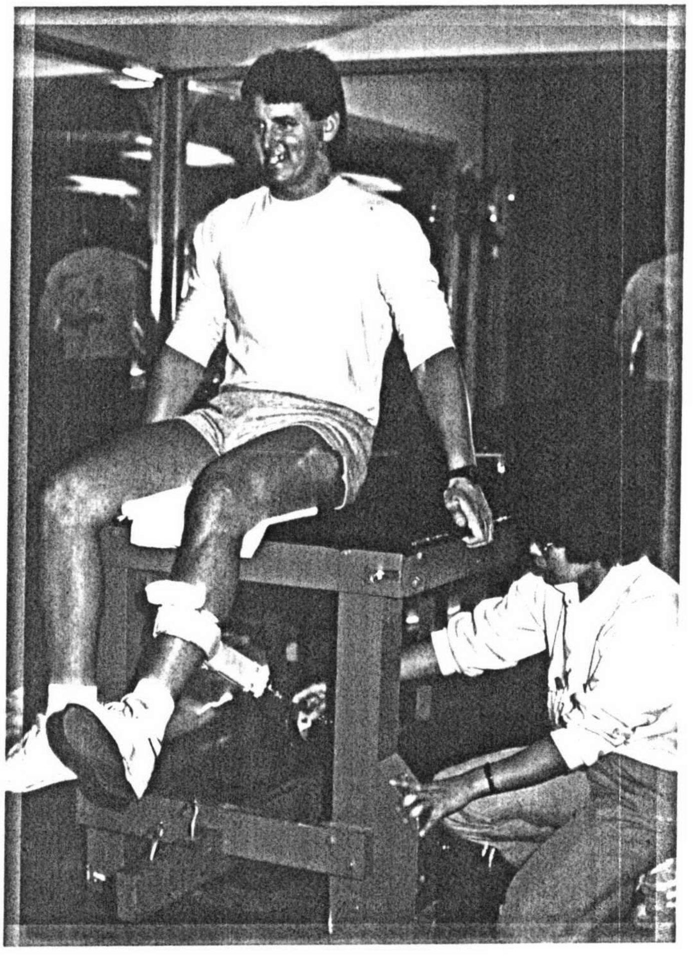


Figure H.3. Dynamic leg strength and leg power test with a Cybex II dynamometer.