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THE EFFECTS OF PLYOMETRIC TRAINING ON THE VERTICAL JUMP PERFORMANCE AND SPEED OF UNIVERSITY BASKETBALL PLAYERS.

BY

©

NEVIN S. GLEDDIE

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"A CORD OF THREE STRANDS IS NOT QUICKLY BROKEN"

(Ecc. 4:12b)

UNIVERSITY OF ALBERTA

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled THE EFFECTS OF PLYOMETRIC TRAINING ON THE VERTICAL JUMP PERFORMANCE AND SPEED OF UNIVERSITY BASKETBALL PLAYERS submitted by NEVIN S. GLEDDIE in partial fulfillment of the requirements for the degree of MASTERS OF SCIENCE.

Dr. Dru Marshall

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Dr. Dan Syrotuik

Dr. Larry Beauchamp

Oct 3, 1994

DEDICATION

To my Lord who gives me strength and grants me peace,

and

to the coaching staff and players of the 1993-94 CIAU National Basketball Champions
University of Alberta Golden Bears

ABSTRACT

Given the increasingly competitive nature of sport, coaches and athletes alike are searching for methods of training which will give them a performance advantage. Plyometrics is a form of power training involving maximal muscular contractions in response to rapid stretching of the muscles used in the contraction. Many exercise practitioners and researchers believe that plyometric training is the answer to the problem of how to improve power performance.

The purpose of the present study was to determine whether or not a properly designed plyometric training program would successfully enhance power performance over and above any improvements which may be seen as a result of regular participation in normal sport specific training thoughout a basketball season. Twelve male athletes were recruited from the University of Alberta men's basketball team. Subjects were assigned to one of three groups, and groups entered the study at two week intervals. Vertical jump (VJ), 20 m, and 40 m sprint times were assessed as the dependent variables. A questionnaire designed to assess the success of the plyometric program was also administered.

The study consisted of four phases. In the first phase all subjects strength trained for a minimum period of 8 weeks. The second phase (ie., pre-test) involved determining pre-test baseline scores for the dependent variables. The third phase consisted of monthly retesting during the fourteen week training period. In the fourth phase (ie., post-test) participants were again administered the VJ, 20 m and 40 m sprint tests.

Athletes significantly improved their VJ, 20 m, and 40 m sprints pre- to post-study by an average of 2.14 cm, -0.047 s, and -0.115 s respectively. Individual analyses revealed several factors which may have influenced the results of this study including: a possible interaction between strength and plyometric training, the Christmas layoff, chronic injuries, and the potential for improvement of individual athletes. Information gleaned from the questionnaire indicated that even in cases where there wasn't an actual improvement in athletic performance, athletes felt that they had improved. In addition, athletes found the training to be enjoyable, effective, and efficient.

The increased power performance demonstrated in this study appeared to be due to a complex combination of basketball practice, strength training, and plyometric training. Therefore, it was concluded that plyometric training assists in the development of power performance in elite athletes, and can be successfully incorporated into a basketball training regime.

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LIST OF ABBREVIATIONS

ATP	Adenosine Triphosphate
BMI	Body Mass Index
cm	Centimeter
CMJ	Counter-movement Jump
CNS	Central Nervous System
DJ	Depth Jump
GTO	Golgi Tendon Organ
IF	Intrafusal Fibres
kg	Kilogram
lb	Pound
m	Meter
min	Minute
MS	Muscle Spindle
NR	No Response
PC	Phosphocreatine
s	Second
SJ	Static Vertical Jump
T1	Test 1
T2	Test 2
T3	Test 3
T4	Test 4
T5	Test 5
VJ	Vertical Jump

CHAPTER 1

INTRODUCTION

Given the increasingly competitive nature of sport at higher levels, coaches and athletes alike are searching for modes or methods which will give them a performance advantage. Some have resorted to illegal methods of performance enhancement such as anabolic androgenic steroids, which pose both a health risk and moral dilemma. Others are searching for legitimate training modes which will substantially enhance an athlete's power and speed.

Many exercise practitioners and researchers believe that plyometric training is one solution to the problem of how to enhance power performance (Bompa, 1993; Wilson et al, 1993; Adams et al, 1992; Chu, 1992; Duke & BenEliyahu, 1992; Javorec, 1989; Bielik et al, 1986a; Brown, Mayhew, & Boleach, 1986; Adams, 1985; Radcliffe & Farentinos, 1985; Clutch et al, 1983; Miller, 1982; Polhemus, 1981; Blattner & Noble, 1979). Plyometrics is a form of power training involving powerful muscular contractions in response to rapid stretching of the muscles involved in the contraction.

Unfortunately research on plyometrics to this point is confounded by the inadequacy of the plyometric training programs in many of the studies. Shortcomings of previous studies include insufficient length of training program, inappropriate overload within each training session, inadequate training volume within a given session, inappropriate exercises, and inappropriate subject selection (i.e., junior high, high school or non-athletic university populations, all of whom are unlikely candidates for plyometric training). Furthermore, the majority of the plyometric training programs in existing research consist almost entirely of depth jumps (DJ) (Wilson et al, 1993; Adams, Worley & Throgmartin, 1987; Brown, Mayhew, & Boleach, 1986; Adams, 1984; Clutch et al, 1983; Ford et al, 1983; Miller, 1982; Polhemus, 1981; Steben & Steben, 1981; Blattner & Noble, 1979; Scoles, 1978). Only Clutch et al (1983) have conducted research on university athletes currently training for their team sport. Regrettably this study only pursued the effects of DJ rather than a well rounded plyometric program. Consequently, plyometric training studies have demonstrated mixed results - with some studies showing increased power and speed , and other studies showing no improvement.

Briefly, the above rationale suggests that there is little evidence as to whether a properly designed plyometric training program will enhance power performance over and above any improvements which may be seen as a result of regular participation in normal sport-specific training throughout a season. Therefore plyometric training warrants more research regarding its effectiveness as a mode of power training.

Statement of the Problem

Plyometrics have often been portrayed as an effective mode of power training (Bompa, 1993; Wilson et al, 1993; Adams, 1992; Chu, 1992; Duke & BenEliyahu, 1992; Javorec, 1989; Bielik et al, 1986a; Brown, Mayhew, & Boleach, 1986; Adams, 1985; Radcliffe & Farentinos, 1985; Clutch et al, 1983; Miller, 1982; Polhemus, 1981; Blattner & Noble, 1979). Basketball is a sport within which the need for power is inherent. The purpose of this study was to determine whether or not a male college basketball player's participation in a plyometric program would enhance his muscular power performance (as operationalized by the modified vertical jump test) and anaerobic power performance (as operationalized by the 40 m sprint), and to determine if that program could be successfully implemented within a basketball season. Vertical jump is a traditional measure of muscular power, whereas the 40 m sprint test is a measure of anaerobic power - or more specifically speed (speed being one of the components of power; i.e., POWER = STRENGTH X SPEED). It was hypothesized that a properly designed plyometric program would positively effect the participants power performance over and above those effects due to participation in sport-specific training sessions.

Objectives of the Study

1. The first objective of this study was to determine whether plyometric training would complement regular basketball training such that an athlete's muscle power, as defined by vertical jumping ability, would be enhanced. It was hypothesized that the inclusion of plyometric training in the training regimen would enhance the athlete's muscle power.

2. The second objective was to determine if the inclusion of plyometric training into the regular basketball training program would also positively affect the athlete's speed (anaerobic power), as defined by the 40 m sprint. It was hypothesized that the inclusion of plyometric training into the training regimen would enhance the speed of the athletes.

3. The third objective was to determine whether or not a plyometric program could be successfully implemented within a varsity team's regular season training regime, as indicated by responses to a questionnaire.

CHAPTER 2

REVIEW OF LITERATURE

Definitions

Power/explosiveness, "... is the muscle's ability to display strength as quickly and as forcefully as possible" (Von Duvillard et al, 1990, p.80). A person's capacity for muscular power is displayed in his/her "... 'ability to instantaneously recruit as many muscle fibres as possible' and to maintain that explosion of muscle contracture over a distance" (Von Duvillard et al, 1990, p.81). *Muscular power* is exhibited in short powerful bursts of muscle contraction and relies exclusively on the stores of ATP within the muscle. *Anaerobic power* also involves maximal contractions of the muscle but these contractions are repeated rapidly for longer periods of time (2-10 seconds), and therefore rely on PC as well as ATP stores. Given the components of power (ie., strength and speed) it is evident that power is an essential ingredient of many sports and athletic events.

Proprioceptors located in muscle, tendons, and ligaments are responsible for transmitting sensory reports from these areas to the Central Nervous System (CNS) regarding orientation, angle of joints, degree of muscle shortening/lengthening, and velocity of the stretch (Chu & Plummer, 1984). *Concentric/isotonic/dynamic contractions* are contractions in which the muscle develops tension while it is shortening. *Eccentric contractions* are muscular contractions in which the muscle develops tension while lengthening.

Athletic performance is defined by a person's ability to jump high or far, or to run fast. *Skill performance* is defined as a person's ability to execute skills specific to his/her sport. *Game performance* is the ability to combine both athletic and skill performance effectively.

The term *plyometric* arose either from the Greek root words "plio" and "metron" meaning more and measure, respectively (Lombardi, 1989), or from the Greek word "pleythyein", meaning to augment or increase (Radcliffe & Farentinos, 1985). Von Duvillard et al (1990, p.80) defines plyometrics as, "...a resistance-training activity that involves an interaction between muscles and the central nervous system (CNS) that decreases the time between the eccentric (lengthening) contraction and concentric contraction of the muscles, providing a more forceful movement of the body." More simply stated, plyometrics is a form of power training involving powerful muscular contractions following a rapid, dynamic loading or stretching of the muscles involved in the contraction. Because these movements occur naturally in many sports (eg., in basketball a player jumps to shoot and upon landing immediately jumps again to go after the rebound), plyometrics can be a very sport-specific method of training.

The Principle of Plyometrics

Plyometrics gained impetus and recognition in Russia and Eastern Europe due to their purported successes in track and field in the mid 1960's (Radcliffe & Farentinos, 1985). The basic premise of plyometric training, which has evolved through research and practice, is to stimulate changes in the neuromuscular system and sensory-motor pathways, thus increasing the muscle's ability to respond more quickly and powerfully to slight and rapid changes in the muscle length. Chu, in Duda (1988, p.214), states that, "All sports activity depends on an individual's ability to overcome the inertia of his or her own body weight or of an external object." It is believed that if the expected neuromuscular adaptations to plyometric training do occur, athletes will be able to reduce the time needed for change of direction, and as a result increase speed and, consequently, power. Thus it is often stated that plyometric training bridges the gap between strength training and the application of skills used by athletes (Lundin & Berg, 1991; Lombardi, 1989; Yessis, 1989; McFarlane, 1985; Chu, 1983; Mann, 1981).

Chu (1983) delineated three phases of plyometric movement. The first phase, entitled the *eccentric phase*, is the rapid loading of the muscle fibre and associated tendon immediately prior to the muscular contraction. In this phase there is loading - or stretching - due to gravity or backswing. Veroshanski called this the *yielding phase* (Radcliffe & Farentinos, 1985). The *amortization phase* is the second phase described by Chu, and it is the short period between the initiation of the eccentric phase and the reflex muscle contraction. Chu's third and final phase, the *concentric phase*, is the contraction of the muscle - both voluntary and involuntary. Veroshanski combines the last two phases into one and entitles it the *overcoming phase* (Radcliffe & Farentinos, 1985).

The Physiology of Plyometric Movement

Power in plyometric movements is supplied by both voluntary and involuntary sources. The primary function of plyometric training is to positively effect the latter of the two. These involuntary sources are the stretch (myotatic, or muscle spindle) reflex, and the elastic properties of the muscle.

Stretch/Myotatic Reflex:

Muscle spindles (MS) are mechanoreceptors (proprioceptors) which respond to both the magnitude and rate of change of length of muscle fibre. They are widely distributed throughout muscle tissue, although there are relatively more MS in muscles requiring complex movements than in those responsible for gross movements (McArdle, Katch & Katch, 1991).

Each MS consists of 5-9 special muscle fibres called intrafusal fibres (IF). The central portion of these fibres lack the ability to contract because they contain neither actin nor myosin. End portions of the IF fibres, which attach to the connective sheaths of skeletal muscle, do contain actin and myosin and therefore can contract. There are two different types of IF fibres: nuclear bag fibres and nuclear chain fibres. Nuclear bag fibres have large central bulges filled with cell nuclei, whereas their counterpart, the nuclear chain fibres, are narrower with single chains of cell nuclei at the centre (Radcliffe & Farentinos, 1985).

Both sensory and motor neurons are involved in the innervation of the MS. Primary sensory neurons are located at the centre of the nuclear bag and nuclear chain IF fibres. The annulospiral endings of these primary sensory neurons coil around the IF fibres and receive information regarding change of length of the IF fibres. The primary sensory neurons associated with these endings are very large, and therefore can transmit nervous impulses to the central nervous system (CNS) very rapidly (approx. 80-120 meters/sec.) (Lombardi, 1989).

There are also secondary receptors, located on either side of the primary sensory neurons, which innervate the MS. Similar to the primary neurons these secondary receptors are associated with the central non-contractile portions of the IF, but these neurons are much smaller and therefore are slower (Radcliffe & Farentinos, 1985).

Because IF fibres are attached at both ends, to skeletal muscle fibres, when skeletal muscle length increases, there is a simultaneous change in length of the IF which in turn causes stretching of the coil-like endings of the sensory receptors. This uncoiling of the annulospiral endings initiates a flux of nervous impulses sent to the spinal cord by afferent sensory neurons. This briefly summarizes the sensory function of the MS (Radcliffe & Farentinos, 1985).

The MS initiates two basic motor responses to stretching of the skeletal muscle: static and dynamic. A static response occurs when the IF is stretched slowly as a result of a gradual skeletal muscle stretch, or by direct stimulation of the gamma-efferent system.

It is, however, the dynamic response of the MS which is thought to be most associated with plyometrics (Radcliffe & Farentinos, 1985). When the primary receptor responds to rapid stretching of the IF around which it is coiled, there is a dynamic response which causes an influx of a large amount of nervous impulses to the spinal cord. These impulses are then relayed immediately back to the skeletal muscle via the alpha motor neuron, causing the stretched muscle to forcefully contract. In this type of response, the rate of stretch appears to be more important than the magnitude of the stretch. This dynamic response dissipates quickly leaving only a static level of nervous conduction.

In terms of Chu's three phases of plyometric movement, the myotatic reflex can be described as follows. In the *eccentric phase* the skeletal muscle fibre is rapidly loaded by an external force (eg., gravity) causing a rapid stretch. In the following *amortization phase,* this lengthening of the fibre is detected by the annulospiral endings within the MS producing a dynamic surge of nervous impulses to the spinal cord via the afferent neuron of the primary receptor. This neuron synapses directly with the alpha motor neuron in the spinal cord, sending a powerful impulse back to the skeletal muscle. The resultant action is a powerful contraction of this muscle to overcome the external force - the *concentric phase*. Thus, "...the result of plyometric training is not the speed of the neural response, but rather the motor units which are called upon to perform an explosive task" (Brittenham, 1992, p.21).

Radcliffe & Farentinos (1985) suggest that in the development and use of human power the contribution of the mind should not be overlooked, because the mind drives and coordinates skeletal muscle. This is particularly true regarding stimulation of the IF fibres via the gamma-efferent system. These gamma-efferent (motor) neurons innervate the contractile ends of both the nuclear bag and nuclear chain IF fibres, and are responsible for increasing or decreasing the threshold of response to skeletal muscle stretching. When the gamma-efferents are stimulated the ends of the IF's contract causing the nuclear bag fibre to pre-stretch - the result being an increased sensitivity of the primary receptors to any lengthening of the surrounding skeletal muscle. Therefore, stimulation of these efferent neurons is very important for eliciting a powerful dynamic myotatic reflex. Furthermore, it is thought that this gamma-efferent system can be used to consciously regulate muscle spindle reactivity (Radcliffe & Farentinos, 1985). Regions of the brain stem, cerebellum, and cerebral cortex are known to be associated with gamma-efferent control (Radcliffe & Farentinos, 1985). This is obviously a critical component of plyometric theory and therefore, during training, the athletes should be encouraged to concentrate on changing direction as quickly as possible.

Elastic Properties of Muscle:

As was mentioned earlier, there are two involuntary contributing forces to a plyometric contraction: the myotatic reflex and the elastic properties of muscle. Cavagna et al (1977) found that there was more energy produced than expended during running. They have suggested that the difference is largely due to the elastic properties of the muscle. Several parts of the muscle are non-contractile but elastic such as the muscle fibre sheath where it connects to the tendon, cross membranes of fibres, and tendons (Radcliffe & Farentinos 1985).

This stretching produces an elastic energy potential which, when released, complements the energy of muscle contraction. Interestingly, Wilson, Elliott, & Wood

(1992) found that individuals who were more flexible had a greater potential to store and release elastic strain energy, thus facilitating greater initial concentric performance. Lundin & Berg (1991, p.24) state that the "ability to change quickly from a lengthening (*eccentric phase*) to a shortening contraction (*concentric phase*) is the key to using the elastic structures of the muscle." While it is difficult to ascertain the relative contributions of the two mechanisms, one can easily see how the myotatic reflex and the elastic potential of the muscle interact. It appears that in plyometric activity, elastic energy released during the *concentric phase* of contraction is enhanced by the myotatic reflex and the associated shorter amortization phase (Lundin & Berg, 1991; Radcliffe & Farentinos, 1985).

Golgi Tendon Organ:

The golgi tendon organ (GTO) is another proprioceptor that responds to stretch and increased muscle tension at a reflex level via the spinal cord. While the GTO's may work with the MS's in overall control of muscle contractions and body control, ..."the ultimate function of the Golgi tendon organs is to protect the muscle and its connective tissue harness from injury due to an excessive load" (McArdle, Katch & Katch, 1991, p.381). Stated another way, the GTO responds to excessive forceful contractions and/or stretching of the muscle by causing the muscle to relax (Radcliffe & Farentinos, 1985).

Obviously if the athlete is concerned about maximizing his or her power output the GTO works in opposition to the MS. However, Lundin (1986) contends that one adaptation in neuromuscular function, due to plyometrics, is a decrease in the inhibitory function of the GTO (ie., there is an increase in the firing threshold of the GTO so that there is greater tolerance for increased stretch loads in the muscle). He further suggests that this phenomena partially explains the ability of plyometrics to increase the possibility of storing a greater amount of elastic energy within the muscle and tendon during the stretch of the eccentric phase. This is predicated on the assumption that GTO inhibition allows a greater loading of the muscle during the eccentric phase, which will then increase the amount of stored elastic energy. In addition, Lundin (1986) submits that GTO inhibition, because of the greater stretch allowed, may elicit a greater myotatic reflex - which in turn will result in a more powerful ensuing contraction.

Plyometric Training: Program Considerations

In order for plyometric training to be a safe and effective training modality, certain execution guidelines must be adhered to. Javorek (1989) asserts that ignorance of correct technique and other program considerations are major causes of injury and poor performance from plyometric training. Radcliffe & Farentinos (1985) have recommended a number of guidelines which will be more definitively explained in the following section. The following guidelines are presented in random order.

1.The Principle of Specificity:

The specificity principle implies that in order to improve performance, neuromuscular and metabolic systems utilized in the given activity must be overloaded in training. Specific exercises elicit specific adaptations, thus creating specific training effects (McArdle, Katch & Katch, 1991). Yuri Veroshanski, a Russian jump coach who many consider the father of plyometrics, developed what he termed the "dynamic correlation" concept. This theory suggests, "...that jumping strength can be optimized by attempting to model the strength training as closely as possible to the function that was to be improved" (Lundin, 1989, p.37). This is one of the greatest advantages and underlying principles of plyometric training - to imitate and overload sport specific movement such as a one legged take-off for a lay-up in basketball (Chu, 1983). In summary, to incorporate the principle of specificity into the training program the athlete must exercise the target muscles, and simulate the activity's movement patterns, duration, resistance, repetitions, and speed (Radcliffe & Farentinos, 1985).

2.Proper Foundation:

Bielik et al (1986a) suggested that without an appropriate strength base the athlete will be unable to withstand the extreme forces created by plyometrics. Researchers have recommended that, as a general guideline, the athletes develop a base of strength which enables them to squat 1.5-2.0 times their body weight prior to implementing plyometrics into their lower body power program (Bielik et al, 1986a; Verhoshanski & Lazarev, 1989). Due to the intermittent stress weight training places on the ligaments, the ligaments thicken and strengthen thus reducing the chance of ligament injury (Wathan, 1983). In addition, a weak athlete will tire easily and therefore be unable to complete a quality workout which, for plyometrics, demands 100% effort.

The question remains: how to incorporate weight training into the training calendar? Semenick & Adams (1987) have suggested that a power training program should begin with strengthening of the muscles of the *jumping chain*, namely the: gluteals, quadriceps, hamstrings, gastrocenemius, soleus, trapezius, and deltoids. Yessis (1991) suggests that it is most beneficial to begin plyometric training after 8-10 weeks of weight training (providing the necessary strength base has been acquired) since it is at this point that the positive power effects of strength training begin to plateau.

Bielik et al (1986b) recommend that when training with plyometrics and weights simultaneously they should be done on alternating days or if done on the same day plyometrics should be done first. They further suggest that the trainer separate plyometrics and weight training by at least 3-4 hours for maximum return from both training modalities. The underlying assumption in this argument is that when weight training precedes plyometrics, the ability of the athlete to perform maximally is decreased and the risk of injury due to fatigue is increased.

3.Warmup:

Lombardi (1989) states that a plyometric workout must be preceded by a extensive general and specific warmup. Radcliffe & Farentinos (1985) suggest that this warmup consist of jogging, form running, and stretching. Since it is believed that nervous conduction is more efficient when the tissues are warm, a good warmup is necessary for maximum performance as well as prevention of injuries (Semenick & Adams, 1987).

4.High Intensity:

Chu (1983, p.21) maintains that... "The neuro-muscular system utilizing the *stretch reflex* principle demands that each effort require the utmost in concentration and physical effort." In addition, Lundin (1989, p.38) states that, "There should be minimal hesitation between the eccentric and concentric contractions of the muscle to capitalize on the increase in MS activity and to maximize the storage and release of elastic energy in the muscle itself." Research by Gollhofer et al (1987) suggests that this myotatic reflex is fatiguable and therefore trainable. This, however, can only occur if the training is executed with the amount of intensity necessary to elicit the desired neuromuscular responses referred to by Chu. Therefore, plyometric training must be done at maximal intensity.

5.Progressive Overload:

Radcliffe & Farentinos (1985) suggest that resistance (amount and distances), temporal (time and intensity), and spatial (range of motion) overload must be employed in order to obtain maximum benefit from the plyometrics program. In order to achieve this goal the athlete must regulate the weight used, utilization of momentum and gravity, height dropped, distances covered, intensity, and stride length.

Lombardi (1989) asserts that a logical stepwise progression is critical in planning a plyometric program. Bielik et al (1986a) contend that it is important to first learn technique. Landing technique, a short amortization phase, coordination of the arms, and maintaining upright posture as well as other safety concerns mentioned in Table 1 (p.16) should be a primary focus in the early stages of a plyometric program.

It is also recommended that a plyometric program should progress from general to specific exercises (Lundin, 1986; Bielik et al, 1986b; Chu & Plummer, 1984; Kroll et al, 1984). An example of a general exercise might be a tuck jump with knees up, whereas a specific exercise might be cone hops with a change-of-direction sprint. Bielik et al (1986a) suggest that the athlete may increase the level of the drill after 3-6 weeks of training at the previous level. Brittenham (1992, p.21) states that, "...progressive plyometric training enhances the recruitment of a greater number of muscle fibers to perform the *same* task."

6.Perform Optimal Number of Repetitions:

It is generally agreed that a plyometric training session should consist of a combination of 3-5 exercises, in 3-10 sets of 4-10 repetitions resulting in a total of 100-200 contacts/session, depending on the intensity of the exercises selected (Von Duvillard et al, 1990; Soviet#2, 1987; Bielik et al, 1986b; McFarlane, 1985; Radcliffe & Farentinos, 1985). Just as there should be a gradual progression in the number of exercises, sets, and contacts per session, there should also be a progression in the number of sessions/week (Lundin, 1986). It is suggested that plyometric training be conducted once a week in the initial stages, progressing to twice weekly later in the training calendar (Von Duvillard et al, 1990; Bielik et al, 1986a; Adams, 1985-86; McFarlane, 1985; Costello, 1984). The major consideration in planning training sessions is that there be adequate recovery between work outs.

7.Proper Rest:

Because plyometrics require an effort of maximum intensity there must be complete recovery to reduce the chance of injury from the high stress loads elicited in plyometric training. Therefore, there must be adequate recovery between sets and exercises.

Rest periods should consist of light exercise and stretching (Bielik et al, 1986b). Bielik et al (1986b) contend that for activities of low amplitude and longer duration, rest periods can be shorter, as compared to activities of high amplitude and short duration, which require longer rest periods. In general, however, a rest of 1-4 minutes between sets, and slightly more between exercises is adequate (Chu, 1992; Von Duvillard et al, 1990; Bielik et al, 1986b; Radcliffe & Farentinos, 1985). Refer to Table 1 (p.15) for information regarding signs of fatigue or overtraining.

It is also important to taper plyometric training prior to competition. Adams (85-85, p.26) states that, "Since plyometric training tends to temporarily slow the nerve muscle response, plyometric training should be discontinued before major competition." It is recommended that the athlete taper plyometric training 7-14 days before a major competition or championship period (Bielik et al, 1986b; Adams, 1985-86; McFarlane, 1985; Kroll et al, 1984).

8.Individualization of the Program:

A good training regime should be designed according to such factors as: the athlete's needs, athletic ability (i.e.,coordination), maturity, fitness (i.e., strength, flexibility and aerobic condition), experience with plyometric training, and weight (Lundin, 1986). First and foremost the trainer must take into consideration the goals of the athlete and coach. Caution must be exercised when dealing with children and adolescents because they are more succeptable to injury since their musculoskeletal systems are still relatively immature (Brzycki, 1986). Another important factor in planning a plyometric program is the weight of the athlete. Athletes who weigh 200 lb or more should be treated with care (Bielik et al, 1986a; Kroll et al, 1984). Kroll et al (1984) recommend that these athletes place less emphasis on the deceleration phase and more emphasis on the acceleration of jumping mechanics. For a safe and effective program the frequency, duration, intensity, and volume of training must be determined by the forementioned factors (Bielik et al, 1986a; Adams, 1985-86; Radcliffe & Farentinos, 1985; Kroll et al, 1984).

9.Safety:

The National Strength and Conditioning Association (1993, p.16) released a position statement regarding plyometric training which states that... "carefully applied plyometric exercise programs are no more harmful than other forms of sports training and competition, and may be necessary for safe adaptation to the rigors of *explosive* sports." The biggest problem with plyometric training is overkill - in terms of intensity, duration, and doing too much of one specific exercise (Duda, 1988). Brzycki (1988), an avid critic of plyometrics, contends during plyometrics the musculoskeletal system is exposed to extreme biomechanical loading; and the muscles, bones, and connective tissue act to absorb this stress. He cites that potential injuries due to plyometrics are: heal bruises, shin splints, meniscal damage, patellar tendinitis, vertebral compression, and various strains, sprains and stress related fractures (Brzycki, 1988, p.37). Evans (in Duda, 1988), states that he sees "...as many problems related to that jump (depth jumping) as from any other training drill." The N.S.C.A. position statement (1993, p.15) suggests that DJ should only be used by a small percentage of athletes participating in plyometric training. Obviously, given the serious nature of some of these injuries precautions must be taken when executing plyometrics. Table 1 contains a number of safety considerations for plyometric training.

10.Technique:

Proper technique is critical for successful plyometric training. When executing plyometric exercises it is important that the athlete maintain upright posture with his/her base of support under his/her center of gravity, the movement of the arms is properly synchronized with the legs, and that the amortization phase is as short as possible. Radcliffe & Farentinos (1985) recommend a locked ankle landing to facilitate a shorter amortization phase, and that a "knees up/thumbs up" policy be adopted. They suggest that when the knees are brought upward quickly, the shoulders tend to drop forward, and that keeping the thumbs up will help to counteract this tendency by forcing the torso more upright.

TABLE 1: PLYOMETRIC TRAINING CONSIDERATIONS

Safety Consider-ations	- proper warmup/warmdown - appropriate strength base - correct technique - resilient surface - proper progression - supportive shoes - adequate equipment - base of support under centre of gravity - execution, not repetition is the key - strengthen antagonist muscles - don't overtrain - adequate rest - never train when fatigued (Soviet #1, 1987, p.82; Bielik et al, 1986b, p.23)
Signs of Fatigue	- too much time spent on the ground - difficulty remaining erect at ground contact - reduced vertical height or horizontal distance - reduced range of motion of extremities - loss of synchronization of arms and legs - loss of arm speed (Lundin, 1986, p.10; Bielik et al, 1986b, p.14)
Signs of Overtraining	- general sense of staleness - abnormally quick onset of fatigue - slow walking movements with poor posture between sets - inability to recover after an intense set - lack of good arm and leg speed - lack of good resiliency of the muscles - excessive joint soreness (Bielik et al, 1986b, p.14)

Critical Review of Training Studies

> "Studies of plyometrics are limited, with only a few writers investigating the effects of plyometrics in conditioning programs. It is difficult to make specific conclusions about plyometric training because of the variety of experimental designs and methods used by the investigators" (Lundin & Berg, 1991, p.25).

In addition, most plyometric training studies in the literature involve depth jumps (DJ) rather than the multiple vertical and horizontal jumps which make up the bulk of most programs (Wilson et al, 1993; Lundin & Berg, 1991; Adams, Worley, & Throgmartin, 1987; Brown, Mayhew, & Boleach, 1986; Adams, 1984; Clutch et al, 1983; Ford et al, 1983; Miller, 1982; Blattner & Noble, 1979; Scoles, 1978). Despite these limitations several of the studies found that plyometrics do have a positive effect on VJ and/or speed performance (Wilson et al, 1993; Adams, 1992; Duke & BenEliyahu, 1992; Brown, Mayhew, & Boleach, 1986; Clutch et al, 1983; Miller, 1982; Polhemus, 1981; Blattner & Noble, 1979). Other studies, however, were unable to elicit the desired adaptations (Adams, Worley & Throgmartin, 1987; Adams, 1984; Ford et al, 1983; Steben & Steben, 1981; Scoles, 1978). Regardless of the results of the studies, from a training perspective, there are a number of problems with the existing research on plyometric training.

Studies Unable to Elicit the Desired Adaptations:

Adams, Worley & Throgmartin (1987) studied the effects of plyometrics and weight training on the muscular leg power of 12-15 year old male football and basketball players. Subjects were divided into two groups according to sport. The basketball group trained with weights and max VJs, whereas the football players trained with weights and .56m DJs (1 set of 20 reps increasing by 5 reps every two weeks). Subjects trained on alternating school days for ten weeks. The researchers found no significant differences in power (as operationalized by a max VJ test and 50m sprint) between groups. Some of the problems with this study include: a failure to factor out rapidly changing maturity of athletes of this age, failure to randomly assign the subjects to training groups thus lending to the confounding influence of athletic types and the differences of training between sports, and too many repetitions per set of DJ.

An earlier study by Adams (1984) sought to investigate the effects of plyometric training on the muscular leg strength and power of 12-17 year old males and females. Subjects were divided into six groups. Subjects in groups 1-4 performed DJ ranging from .61m to 1.5m depending on the group the individual was assigned to. Group 5 was a control group which participated in non-jumping activity, and group 6 participated in vigorous activity including jumping. Subjects trained 3 times per week for 7 weeks. Power was measured using a VJ and standing long jump test. Strength was measured with a cable tensiometer at two knee joint angles. Significant differences were not demonstrated in the VJ and standing long jump tests, but significant gains in isometric strength were found. Adams (1984) suggests that plyometrics are of greater value to more highly trained athletes. There are several problems with the study including: too short a duration, not enough contacts per training session, too many repetitions per set, and the risk of untrained subjects of this age executing DJ of such magnitude.

Ford et al (1983) studied the effects of three combinations of plyometric and weight training programs on the sit-up, 40 yard dash, VJ, shuttle run, and pull-up scores of 50 high school boys. Subjects in the plyometric groups (groups 1 and 3) trained using DJs and form running. Depth jumps were performed with a 20lb weighted vest. Group two was the control group and as such weight trained but performed no plyometrics. Subjects trained 5 times every 2 weeks for 10 weeks. Each group showed significant improvement from pre to post test on the sit-up, 40 yard dash, VJ, and pull-up tests, but none of the groups showed significant improvement on the shuttle run. However, there was no significant difference in effect between the plyometric groups and the weight training group. Problems with this study include: not enough training volume per session, a lack of progression, and the risk of using a weighted vest for beginners.

Steben & Steben (1981) studied the effect of various forms of plyometric training on the high jump, long jump, and triple jump performance of grade 7 and 8 males and females. Subjects were randomly assigned to one of four groups, and trained 10 minutes per day, 5x per week, for seven weeks. Group 1 trained with .25m DJs, Group 2 with box drills specifically designed for triple jump, Groups 3 with flexibility-agility exercises, and Group four - the control - participated in various warm-up type drills. No significant differences were found among the training groups, however, significant pre-post test differences were found for each dependent variable in each group (including the control). Notable problems with this study include: a lack of progression, too short a duration, not enough recovery between session, not enough volume per session, and the skill components of the dependent variables.

The purpose of Scoles' (1978) study was to determine the effects of depth jumping on the VJ and standing long jump performance of college males. Subjects were randomly assigned to 3 groups. Group 1 performed DJ training, Group 2 flexibility training, and Group 3 was the control and as such participated in only the regular class activities. Subjects in the DJ group performed 20 .75m DJ per session. All subjects trained 2 times per week for 8 weeks. Scoles (1978) found that DJ did not significantly improve VJ and standing long jump performance. Problems with this study include: too short of a training period, not enough volume per session, and too intense of a program for beginners (ie., 0.75m DJ).

As previously mentioned, most of the plyometric training programs studied consisted almost exclusively of DJ's. One of the problems with this type of program is that there is no logical stepwise progression of overload, as suggested by Lombardi (1989). By skipping the steps prior to implementing DJ, the athlete is neither prepared for the high impact stress of this form of training nor does the athlete possess the necessary strength base to perform maximally. For example, Adams (1984), had children ages 12-17 years performing 20 reps/session of .61-1.5m DJ. This is an enormous load for an untrained subject, particularly for such young athletes. Chu (1992) recommends that athletes at this age always begin with gross motor plyometric activities of low intensity (eg., double leg bounding).

A glaring difference between the studies which demonstrated an increase in power performance and the studies that didn't, was the age of the subjects. Four of the five studies which failed to demonstrate an increase in power performance involved subjects from junior and senior high schools (12-18 years of age), whereas subjects in six of the eight successful studies were recruited from college and university undergraduate populations. It is likely that little benefit was seen as a result of the plyometric training due to the inadequate strength base of the younger subjects. Furthermore, as mentioned in the previous paragraph, athletes at this age should not be executing DJ.

Adams, Worley & Throgmartin (1987) studied the effects of max VJ and DJ on leg muscle power and attempted to incorporate some form of overload. However, given the nature of their training regime, they encountered problems. They had their DJ group executing 20 consecutive jumps from .56m, and the number of jumps were increased by 5 every two weeks. There are two inherent problems in this protocol. Firstly, Bielik et al (1986a) suggest that the level of intensity of the drill should be increased after 3-6 weeks of training at the previous level. Secondly, it has been recommended that plyometric drills be conducted in sets of 4-10 repetitions - not 20 or more repetitions as seen in this study (Von Duvillard et al, 1990; Soviet#2, 1987; Bielik et al, 1986b; McFarlane, 1985; Radcliffe & Farentinos, 1985).

Another limitation of these studies was their duration. The studies which found plyometrics to have a positive effect on power performance averaged 10.3 weeks as opposed to the average 8.4 weeks of those studies unable to elicit a positive response. It appears that training adaptations become most apparent after 10-16 weeks of plyometric training (Wilson et al, 1993; Brown, Mayhew & Boleach, 1986; Clutch et al, 1983). Inadequate rest appears to be another limiting factor of these unsuccessful studies. For example, Ford et al (1983) allowed only a 1:1 work to rest ratio between bouts of DJ and form running. Chu (1992) recommends a work:rest ratio of 1:5-1:10.

The study by Steben & Steben (1981) did not allow enough rest between training sessions. They had grade 7&8 males and females executing either DJ, box drills, or flexibility-agility (eg., hops and bounding) five times per week. It has been recommended that plyometrics be performed 1-3 times per week, with at least 24 hours between sessions (Von Duvillard et al 1990; Bielik et al, 1986a; Adams, 1985-86; McFarlane, 1985; Costello, 1984).

Studies in Which the Desired Adaptations Were Obtained:

Wilson et al (1993) attempted to determine which of three power training methods most positively affected selected power performance criterion. Wilson and his associates recruited 64 subjects, who had been weight training for at least one year prior to the study, and randomly assigned them to one of four groups. All groups (with the exception of the control group) trained twice per week for 10 weeks, completing 3-6 sets of 6-10 reps per session of their designated exercise. The weight training group performed squats utilizing the *Plyometric Power System*. Those in the plyometric group performed DJ beginning at a height of 0.2 m and progressing to 0.8 m over the ten week period. Subjects in the dynamic weight training group performed jump squats using the *Plyometric Power System* bearing a weight approximating 30% of their maximum isometric force. Controls were instructed to continue their current training regime. Prior to, after 5 weeks, and following the 10 week training period subjects completed the following power tests: 30 m sprint, counter-movement jump (CMJ) and static VJ (SJ), 6-s cycle test, peak torque for leg extension (Cybex), and a maximum isometric squat. All three training groups significantly increased their CMJ (5% weight training, 10% plyometric training, and 17%dynamic weight training). Only the weight training group and dynamic weight training groups significantly increased their SJ. Furthermore, only the dynamic weight training group significantly decreased their sprint times. One of the problems with this study was that VJ tests were conducted in a *Plyometric Power System* apparatus which does not allow for contribution of the trunk and arms. Thus, one of the benefits of plyometric training is negated (ie., that athletes learn how to successfully coordinate their trunk, arms, and legs when jumping). Other problems with this study include: a lack of progression for the plyometric group (ie., DJ only), insufficient volume in the initial stages of plyometric training, and the two test trials were averaged rather than accepting the best score.

Adams et al (1992) attempted to determine which of three training methods most successfully increased vertical jump performance. Forty eight male volunteers from university weight training classes were assigned to one of four training groups. Group 1 trained using squats 2 times per week in a progressive manner. Group 2 executed plyometric exercises (DJ, double leg hops, and split squat jumps) 2 times per week with increasing intensity and decreasing volume. Group 3 completed a program combining the squat and plyometric programs, although volume was reduced by 25% to compensate for the differences in training volume between groups. Group 4 was the control group and no mention is made regarding their training regime. All groups trained for six weeks, however, during the sixth week training tapered off. All groups significantly increased their VJ scores, but those athletes in the squat-plyometric group improved the most. Groups 1-3 improved their VJ scores by 3.3, 3.81, and 10.67 cm respectively. Although the plyometric training protocol in this study demonstrates some degree of progression, as beginners they started at too high a level. An additional criticism of this study is that subjects in group 3 did squats prior to plyometrics once per week. As mentioned earlier, Bielik et al (1986b) recommend that when weight training is done simultaneously with plyometric training, they should be done on alternating days, or if done on the same day, plyometrics should be done first. Despite these limitations Adams et al (1992) did obtain significant results.

Duke & BenEliyahu (1992) studied the effects of weight training and weight training plus plyometric training on vertical jump performance. Ten male high school athletes were assigned to one of two groups (5 basketball players in group 1 and 5 track and field athletes in group 2). The athletes in group 1 trained exclusively with weights emphasizing the muscles of the jumping chain. Group 2 trained using a variety of plyometric exercises in addition to the weight training protocol used by group 1. Both groups weight trained 3 times per week, and group 2 completed the plyometric training 2-3 times per week as determined by the researcher. Both groups improved their VJ scores (0.6 and 2.5 inches respectively). No attempt was made to control for differences between groups or differences in training volume. Furthermore, although the plyometric training regime encorporated a variety of exercises and demonstrated some progression, progression was too rapid, and some exercises were introduced beginning with too many repetitions (ie., week one includes 4X20 squat jumps). Given the weaknesses of the design of this study the results should be interpreted with caution.

Brown, Mayhew, & Boleach (1986) studied the effects of plyometric training on the VJ performance of 26 high school basketball players. Subjects were randomly assigned to one of two groups. Group 1's plyometric training consisted of .45m DJs in 3 sets of 10 reps per session. Group 2, the control, participated only in regular basketball training. During the twelve week training period a total of 34 training sessions were performed. Subjects were pre and post tested on two measures of VJ (with arms and without). The results indicated that the plyometric group performed significantly better on the VJ test with arms (7.3 cm) than the control group. There was no significant difference between the two groups for the VJ without arms test. Although the duration of the training (12 weeks) is quite acceptable there are other criticisms to be made such as: a lack of progression, not enough training volume per session, not a well balanced program since it is composed exclusively of DJs.

In his research, Miller (1982) demonstrated that plyometric training positively effected the VJ performance of adult female subjects. Subjects were divided into two groups, a plyometric group and a control group. The plyometric group performed 5 sets of 10 reps of 0.5m DJ 1 time per week for 8 weeks. Results indicated that the plyometric group increased their VJ scores by an average of more than 5cm. The activity level of the control group was not stated. Further criticisms of this study are: a lack of progression, lack of training volume, short period of training, the exclusion of other modes of plyometric training.

Polhemus (1981) sought to determine the effects of plyometric training on the functional strength of college football players. Athletes were divided into 3 groups: group one was assigned to a conventional weight training program, group 2 did the weight training program as well as a plyometric program (form running, depth jumps, standing long jumps), group 3 participated in the same program as group 2 but with the addition of ankle and vest weights for the plyometric drills. Subjects trained 3 times per week for 6 weeks. Pre-post tests were conducted on VJ, standing jump, and the 40yd. dash. In the final analyses group 3 improved significantly on all three dependent variables while the other two groups did not. Problems with this study include: an obvious lack of progression (particularly for group 3), and insufficient duration of training period.

Blattner & Noble (1979) studied the effects of isokinetic and plyometric training on the VJ performance of college males. Subjects were randomly assigned to one of three groups and then randomly assigned to one of three treatments. Group 1 trained with isokinetic exercises, group 2 trained with plyometric exercises, and group 3 was the control group. The plyometric group performed 3 sets of 10 reps of 34" DJ with no additional weight for the first two weeks, and then beginning with 10 lbs increased the weight of the vest by 5 lbs every two weeks. Subjects in both training groups trained 3 times per week for 8 weeks. No significant differences were found between the two experimental groups, however, both experimental groups were found to be significantly different from the control group. The plyometric group improved their vertical jump 2.05 inches. Problems with this study include: insufficient training volume per session, too short of a training period (particularily since the average subject missed 5/24 training sessions), subjects were overloaded too quickly, and finally these results may be difficult to apply to athletic populations.

Studies Involving Athletes Currently Training for a Team Sport

Clutch et al (1983) conducted two studies on the effects of DJs and weight training on leg strength and VJ. In their first experiment, subjects (undergraduate males) were randomly assigned to one of three groups. Group 1 performed maximum VJs, Group 2 performed .3m DJs, and Group 3 performed .75m and 1.1m DJs. All subjects performed 4 sets of 10 reps per session of their exercise (group 3 performed 2 sets of 10 reps from each of the two designated DJ heights). Subjects trained 2 times per week for 12 weeks. Leg strength was evaluated with a 1RM squat measure and isometric strength measure at a knee angle of 125 degrees. Vertical jump was also pre and post tested. The results of this experiment demonstrated significant improvements in the performance measures (average VJ increase of 8.4 cm) but no significant differences between the treatment programs. Perhaps the failure to demonstrate that DJ are more effective than max VJ training indicates the need for a well-rounded plyometric program, and possibly that DJ need not be included in that program.

In their second experiment, Clutch et al (1983) randomly assigned members of a weight training class and a college volleyball team to one of two groups. Subjects in group 1 did weight training and a DJ program of 4 sets of 10 reps (2 sets from .75m and 2 sets from 1.1m). Group 2 weight trained but did no DJs. All subjects trained 2 times per week for 16 weeks. In addition members of the volleyball team practiced 5 times per week for 2.5 hours. Each subject's maximum VJ was pre and post tested. The results indicated a significant improvement (3.5 cm) in VJ ability, but those who did DJ were not deemed more successful than those who did no DJ. Clutch et al (1983, p.9) concluded that, "...depth jumps are useful for athletes who are doing no other jumping, but they add nothing over and above that which is obtained from normal practice where a good deal of jumping occurs." Problems with this study include: a lack of progression in the plyometric training, lack of training volume per session, and that DJs were the only mode of plyometric training incorporated in this study.

Unsuccessful vs Successful Studies

As in the unsuccessful studies all of the successful studies primarily involved DJ. This is unfortunate because the results of these studies cannot be generalized to the average well-balanced plyometric program. In addition, opponents of plyometric training have expressed deep reservations regarding the use of DJ's for power training (Brzycki, 1988; Duda, 1988).

In their landmark study Clutch et al (1983), however, came to some interesting conclusions. The average subject improved his VJ by 8.4 cm in just 12 weeks. However, they concluded that DJ training had no greater effect on VJ than maximal VJ training. Perhaps this lends credence to the assertion that a well-designed plyometric program should consist of a variety of exercises (Von Duvillard et al, 1990; Soviet#2, 1987; Bielik et al, 1986b; McFarlane, 1985; Radcliffe & Farentinos, 1985).

Another problem with the use of DJ in these studies is that there is not a proper progression of overload as recommended (Lombardi, 1989). Therefore the plyometric training in these studies is too harsh for beginners (Brown, Mayhew, & Boleach, 1986; Clutch et al, 1983; Miller, 1982; Polhemus, 1981; Blattner & Noble, 1979). A good example of inadequate progression is seen in a study by Polhemus (1981). In this study on college football players, one group of subjects were required to perform DJ, horizontal jumps, and form running three times per week wearing 18-20 lb vests and 2.5 lb ankle weights on both ankles. Chu (1992) maintains that it is not advisable for beginners to use weights during plyometric training. He further suggests that even elite athletes should use weights with caution, one time per week in an eight week cycle, and only after a long preparatory period. Although this particular study lasted only six weeks and injury rates were not recorded, one might speculate that a program of this nature might elicit a great deal of injury over an entire season.

A final limitation of those studies which elicited a response is the lack of research on University athletes currently involved in team sport. The second experiment by Clutch et al (1983) was the only study conducted on varsity athletes while training for their sport (volleyball). Unfortunately, in the experimental group the only form of plyometrics they incorporated into the training regime (weight training and regular volleyball practice) was DJ, which is indeed a limitation. Accordingly, Clutch et al (1983) found that the DJ group had no greater gain in VJ than those who simply participated in the regular volleyball practice and weight training sessions.

Conclusion

Given the various problems and limitations of the preceding research regarding plyometrics, there was an obvious need for a comprehensive, well-designed, long-term plyometric training study on varsity athletes involved in team sport. Whether or not these athletes could successfully power train via plyometrics during the season, given the limitations of frequent competition, needs to be examined. Accordingly plyometric training research was conducted on athletes currently training for their team sport (basketball), based on the comprehensive guidelines outlined in this review, and involved a training period of 14 weeks. Information of this nature should prove invaluable to coaches, their athletes, and trainers.

CHAPTER 3

METHODS AND PROCEDURES

Design of the Study

A multiple baseline design across subjects was employed in this study. Participants were drawn from the University of Alberta men's basketball team affording a sample of 12 university males. The participants were randomly divided and assigned to one of three groups, and entered the study at two week intervals in order to rule out the effects of history. Each subject acted as his own control. The plyometric program was considered a part of the team's conditioning and as such it was expected that all athletes would participate, with the following exceptions: 1) athletes who had chronic injuries affecting their participation; 2) athletes who had acute injuries; and 3) those athletes who failed to meet the initial strength requirement following a minimum of 8 weeks of strength training (ie., squat 1.5 times their body weight).

The study consisted of four phases. In the first phase (i.e., weight training) all subjects strength trained for a minimum period of eight weeks (until they were able to squat 1.5x their body weight). In accordance with recommendations made by Semenick & Adams (1987), the strength training program focused on strengthening the muscles of the *jumping chain*, namely the: gluteals, quadriceps, hamstrings, gastrocenemius, soleus, trapezius, and deltoids. Strength training sessions of one hour duration were completed three times per week.

The second phase (i.e., pretest) involved determining pretest baseline scores for the two dependent variables (ie., 40 m sprint and vertical jump). Subjects performed a modified verticle jump test (Sale in MacDougall, Wenger, & Green, 1991; Fleck et al, 1985), and a 40 m sprint timed with an electronic timing system. Subjects were tested morning and afternoon for three days yielding a baseline of six scores per test per subject. Each score consisted of the best of two trials (i.e., 12 trials in total). Both morning and afternoon scores were averaged for data analysis. At all times care was taken to test at the same times each day to determine if a bio-rythm was present.

The third phase (i.e., training) consisted of one day of retesting monthly during the fourteen week training period to track the effects of the intervention on the dependant variables. Two scores (ie., each score consisted of the best of two trials for a total of four trials) were taken per test per subject with the same protocol used in phase two. Subjects trained for 14 weeks, once or twice per week depending on the game and practice schedule, and the progression of the plyometric program.

In the fourth phase (i.e, posttest) participants were again administered the vertical jump and 40 m sprint tests. Similar to the pretest phase, six scores per test per subject were taken over three days and the morning and afternoon scores were averaged. Each score consisted of the best of two trials for a total of 12 trials. Again, care was taken to test at the same times as the pre-tests to rule out the effects of bio-rhythms. These final power tests were administered one week following the completion of the plyometric program. In addition, following the post-testing, a questionnaire (Appendix B) was administered to subjectively determine whether or not the plyometric program was successful. All three phases of testing were conducted on a rubberized indoor track.

Subjects

Subjects were recruited from the University of Alberta varsity men's basketball team. Potential athletes for the 1993-94 season were asked for their cooperation in a cover letter and informed consent form delivered by mail or personally prior to September 30, 1993.

Program Design

Following the initial weight training phase, the participants met once or twice per week depending on the stage subjects were at in the progression of the plyometric training program, for a total of sixteen weeks (including 2 weeks of testing). During this time the subjects received both practical and theoretical instruction regarding plyometric training. The plyometric program consisted of a variety of plyometric exercises of varying intensity excluding DJ. This program was designed by the investigator following the principles of plyometric training as outlined in the preceding literature review. The program incorporated a variety of exercises including various multiple jumps, and forms of bounding and skipping, but excluded depth jumps (Appendix A).

Benefits of the Design

Participants in this study were randomly divided and assigned to one of three groups. In keeping with the multiple baseline design across subjects, once a stable baseline of the dependant variables had been established, the groups began training at two week intervals in order to reduce the effect of history. Another benefit of this design was that it allowed each subject to act as his own control. Furthermore by establishing a baseline with multiple measures for each individual prior to introducing the independent variable (plyometric training) we could ensure with some degree of confidence that any changes that we did see were due to plyometric training.

Limitations of the Design

The primary limitation of this design is that, in keeping with quasi-experimental designs, there was no control group. Without a control group it is difficult to rule out alternative hypotheses, and as a result it is difficult to determine cause and effect.

A second limitation of this design was the practicality of properly periodizing the training for all athletes within a university season (eg., appropriate tapering for competition for all groups). For example, the program was designed such that the third group was able to taper at the appropriate times for major competitions. However, the remaining two groups were finished two or four weeks prior to group three. To ensure that training effects would not be lost, groups one and two were placed on an appropriately periodized maintenance program.

Another potential limitation was that some athletes would be unable to squat 1.5 times their body weight after completing the weight training phase, and therefore would be unable to begin the plyometric program. Thus athletes were given up to a maximum of 12 weeks; if at that time they were unable to perform the criterion squat subjects were dropped from the study cohort.

Another limitation of this study was that there was a possibility that some athletes would not become available until Sept. 1. This did not pose a threat unless an athlete was unable to complete the criterion squat, in which case this athlete would have had to be excluded from the study until such a time as he was able to meet this requirement.

The final limitation was the relatively small number of subjects, and the high potential for subject attrition due to injuries commonly associated with the game of basketball. This unfortunately resulted in unequal numbers in each group. However, with the exception of temporary layoffs due to minor injury, all those athletes who entered the study successfully completed the training program.

Measurements

Height and weight measures were determined by self-report. Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared. Strength training was monitored by the subjects themselves and recorded in their training diary. Playing time was monitored and recorded by the team's manager.

Two measures of power were used to assess the effectiveness of the plyometric program. A modified vertical jump test was used to measure muscular power (Fleck et al, 1985). Briefly, this test involved measuring the difference between the maximum height the athlete could reach in a standing position with the arm fully extended above the head, and the maximum height the athlete could reach using a stationary two foot vertical jump. The protocol was modified allowing the athletes to step into the jump. Stated another way, the athlete had to keep one foot in place but was allowed to swing the other foot into position to gather momentum for the jump. Each athlete performed two trials with a two minute recovery between each trial, and the best of the two trials was taken.

A modified protocol was selected because it is probably more representative of jumping in basketball across situations and positions and therefore had high face validity. A vertical jump measure was included as a dependant variable because good vertical jumping ability is very advantageous in basketball, and as such the measure possesses content validity.

The second measure of power was a 40 m sprint test. An electronic timing system was used to measure the elapsed time at the 20 m and 40 m marks. Subjects started one meter back from the first timing device to avoid triggering the timing system prior to the start. The athletes started in a standing position and waited for the command "GO", which was preceded by the words "READY...SET". Upon hearing the command "GO" the athletes sprinted all out for the full forty meters. Again, each athlete performed two trials and the best of the two was taken. Athletes performed trial 1, were given two minutes of recovery, and then performed trial 2.

This measure also has high face and content validity due the speed necessary for the game of basketball. Furthermore, both of these dependent variables were suitable for measuring the effects of plyometrics.

Data Analysis

Both parametric and non-parametric statistics were used to evaluate the data gathered in this study. Analysis of variance and the sign test were used to test the significance ($p<0.05$) of mean changes in the dependent variables: vertical jump, 20 m sprint, and 40 m sprint. In addition, individual mean changes were utilized for analyses of single subjects. It was hypothesized that plyometric training would assist in improving VJ, 20 m, and 40 m sprint performance.

It should be noted that results which are significant to a coach or exercise practitioner may not always be statistically significant. In an effort to please both the practitioner and the scientist traditional group statistical analyses were performed in addition to a more detailed descriptive and statistical examination of individual mean changes.

CHAPTER 4

RESULTS

Physical Characteristics

Twelve members of the University of Alberta men's basketball team participated in this study. Their average height was 191 ± 13cm, average weight 88.3 ±20.2 kg, the average age was 20.8 ± 2.8 years old, and the average BMI was 24.2. One member of the team was Black, the remaining 11 subjects were Caucasian. All subjects successfully completed the criterion squat of 1.5 times their body weight.

Program Design

During the 14 week training period subjects completed an average of 13 plyometric training sessions, practiced approximately 5.5 hours per week, and completed a strength training maintenance program an average of 13 and 7 times for upper and lower body, respectively. Plyometric training sessions consisted of 3-5 sets, of 8-10 repetitions, of 4-5 exercises.

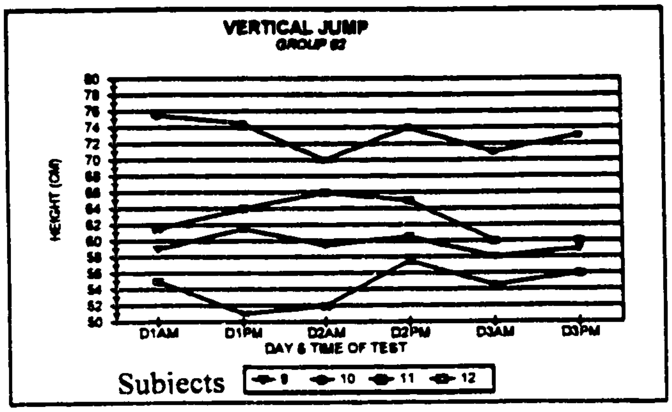
Baseline Measures

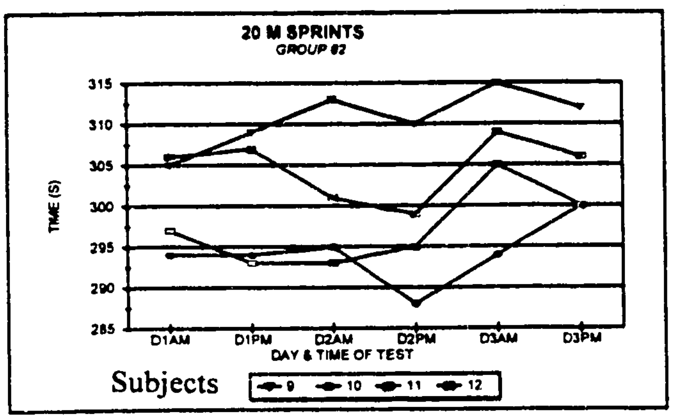
Initial analyses of the baseline measures reveals that these measures were relatively unstable (an example of the baseline measures can be seen in Figure 1: Baseline Measures of Group #2, P.33). This may be due to either error in testing or simple performance variability of the subjects. Given the fact that testing procedures were rigorously controlled, it is unlikely that the instability can be attributed to testing error. Pilot tests were conducted prior to the study to rehearse the testing procedures, and the subjects were given several practice attempts prior to testing. In addition, the testing protocol was standardized with written instructions. Even though testing occurred in the same place, it was difficult to control the environment since it was a public facility. Furthermore, while no motivation was given by the investigator, the subjects themselves motivated and competed against each other. Since the sprint tests were timed electronically, and distances were measured twice prior to each day of testing and confirmed with markings on the floor it is unlikely that there was measurement error in the sprint tests.

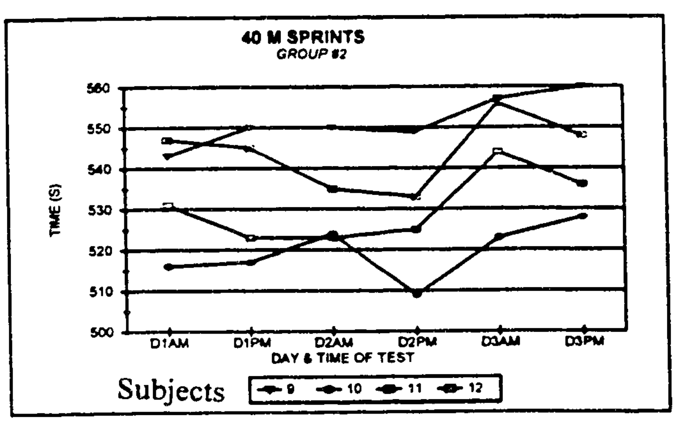
Rather, it appears that the instability seen in the baseline measures was due to performance variability of the subjects or changes in the environment. The instability in the test scores appeared across days and time of day. For example, an athlete might have tested well on Monday and Tuesday, but demonstrated a decline in performance on Wednesday potentially due to soreness from practice Tuesday night. An example of the effect a changing environment might have on performance was supplied by one of the subjects in this study. He did well on his sprint tests in the presence of a girl he was particularly fond of, who was attending a class in the vicinity. Finally, there was a significant biorhythm effect ($p<0.05$), as evidenced by poorer VJ and 20 m sprint performance in the morning than in the afternoon.

Given the presence of the biorhythm effect, the means of the afternoon scores of both the baseline measures and retests were selected for data analyses. This decision was made for the following reasons: 1) to eliminate the effect of the biorhythm; 2) because the afternoon scores were more representative of maximum performance; 3) by utilizing the afternoon scores the data was still representative of performance across three days, thus limiting the effect of a exceptionally good or bad day; 4) the afternoon scores were more representative of basketball performance times (ie., games and practices); 5) use of afternoon scores reduced the effect of stiffness due to prior practice and training; 6) it reduces the effect of the subjects' inability to focus on the task at hand when awakened at an hour earlier than they were accustomed to; 7) by accepting only the afternoon scores a more stable baseline is achieved. There are two problems with the decision to utilize only the afternoon scores: 1) useful information may have been discarded; 2) because the maximum score is not used it is not a true indication of maximum performance. Nonetheless, since the positives of this decision outweighed the negatives, only the afternoon scores were chosen for data analyses.

Figure 1: Baseline Measures of Group #2







Group Statistical Analyses

A summary of the group data is provided in Table 2. ANOVA and the sign test were completed on pre- and post-test scores only.

TABLE 2 : SUMMARY OF GROUP DATA

DEPENDENT VARIABLES	MEAN CHANGE	ANOVA ($p<0.05$)	SIGN TEST ($p<0.05$)
Vertical Jump (cm)	+2.14	0.001*	0.0031*
20 m Sprint (s)	-0.047	0.009*	0.0059*
40 m Sprint (s)	-0.115	0.003*	0.0002*

* = significant result

Vertical Jump

The average increase in vertical jump in this study was 2.14 cm. From a coaching standpoint, this is a significant gain in jumping ability. Results of the ANOVA and sign test confirm this conclusion statistically ($p<0.05$).

20 m Sprint

The average 20 m sprint time was reduced by -0.047 seconds (s). From a coaching perspective this increase in speed should produce noticeable changes in the performance of skills requiring acceleration such as defensive slides and offensive penetration. Statistically these results were also significant ($p<0.05$).

40 m Sprint

Similar to the 20 m sprint results, the 40 m sprint performance also improved significantly demonstrating an average reduction in sprint time of -0.115 s. This increase in speed should be evident in quicker transition from offense to defense and vice versa.

Results of the ANOVA and sign test confirm the statistical significance of this increase in speed ($p<0.05$).

Individual Analyses

A summary of the individual data can be found in Table 3. Notice that 11 of 12 subjects improved their VJ, 10 of 12 subjects improved their 20 m sprint, and all of the subjects in the study improved their 40 m sprint times. Figures 2-4 demonstrate the pre-post- study changes in performance of VJ, 20 m, and 40 m sprints. In addition, Figures 5-7 graph the changes seen in VJ, 20 m, and 40 m sprints for each individual throughout the study. As can be seen in figures 5-7, rarely was there steady improvement throughout the study. It is difficult to make generalizations regarding the individual data, however, often there was improvement between T1 and T2 followed by a decline in performance between T2 and T4, and recovery between T4 and T5. The most obvious trend is a substantial decrease in performance across many of the subjects at T4. A more detailed and descriptive individual analyses of mean changes will follow in the discussion portion of this presentation.

TABLE 3: SUMMARY OF INDIVIDUAL DATA

SUBJ #	Height (cm)	Weight (Kg)	BMI	Age	Plyo. Sessions	Playing Time (min)	DIFFERENCE SCORES		
							VJ (cm)	20 m s	40 m s
1	178	68.1	21.5	22	13	>20	+1.2	-0.03	-0.07
2	196	90.8	23.6	21	14	<10	+3.7	0.00	-0.01
3	196	113.5	29.6	20	13	>20	-1.2	-0.01	-0.12
4	183	74.9	22.4	18	14	<10	+2.4	+0.02	-0.06
5	188	79.5	22.5	20	12	>20	+5.0	-0.08	-0.33
6	191	86.3	23.6	22	9	<20	+2.8	-0.11	-0.21
7	191	93.1	25.5	22	15	<20	+2.2	-0.01	-0.09
8	196	90.8	23.6	21	13	<10	+3.8	-0.09	-0.20
9	201	102.2	25.3	21	14	>20	+1.9	-0.15	-0.22
10	188	85.8	24.3	22	14	>20	+0.9	-0.05	-0.04
11	193	89.4	24.0	20	9	<20	+1.5	-0.02	-0.02
12	191	84.9	23.3	21	14	<10	+1.5	-0.03	-0.01
Mean	191	88.3	24.2	20.8	13.1	<20	+2.1	-0.05	-0.12

*Body Mass Index = weight(kg)/ (height(m))^2

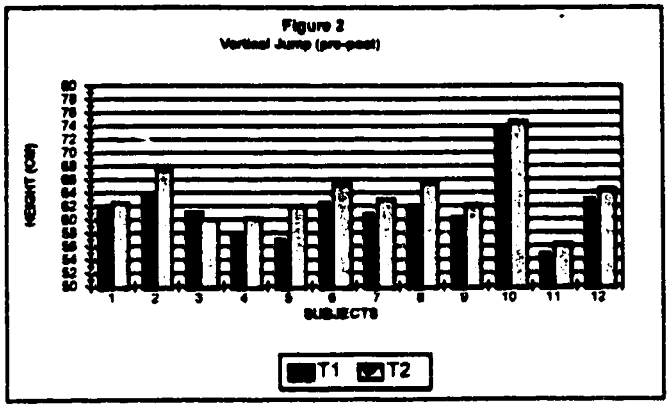


Figure 2
Vertical Jump (pre-post)

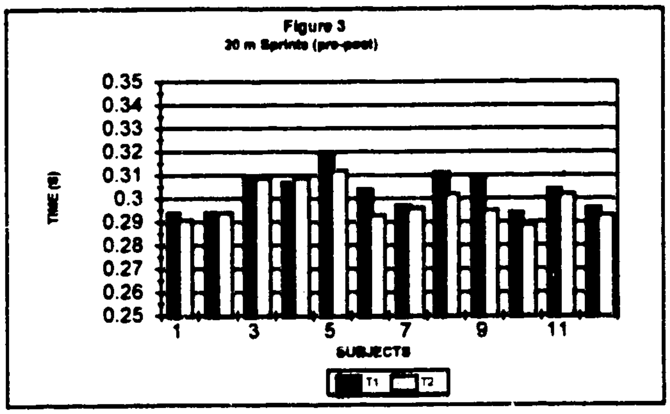


Figure 3
20 m Sprints (pre-post)

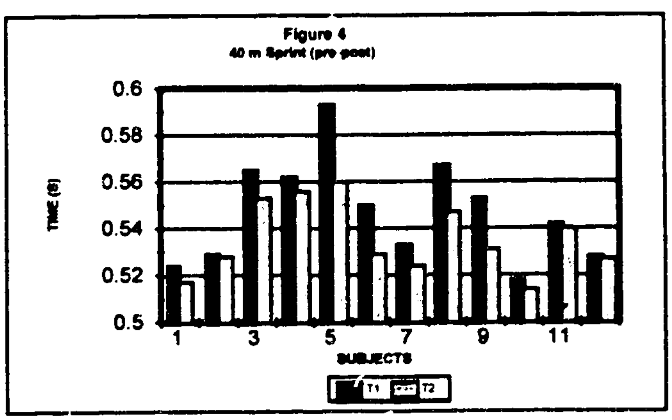


Figure 4
40 m Sprint (pre-post)

Figure 5: Vertical Jump Scores Across 5 Tests

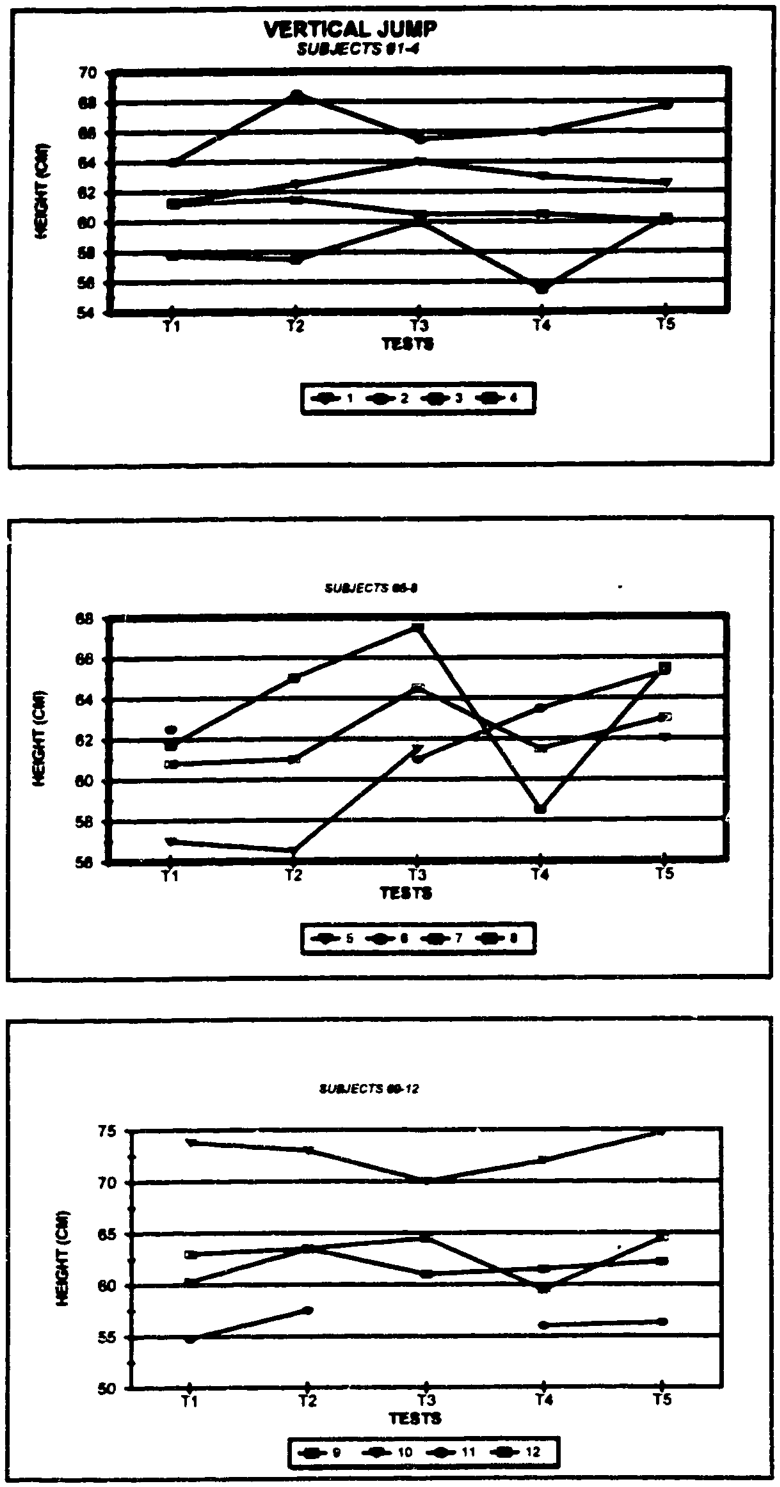


Figure 6: 20 m Sprint Scores Across 5 Tests

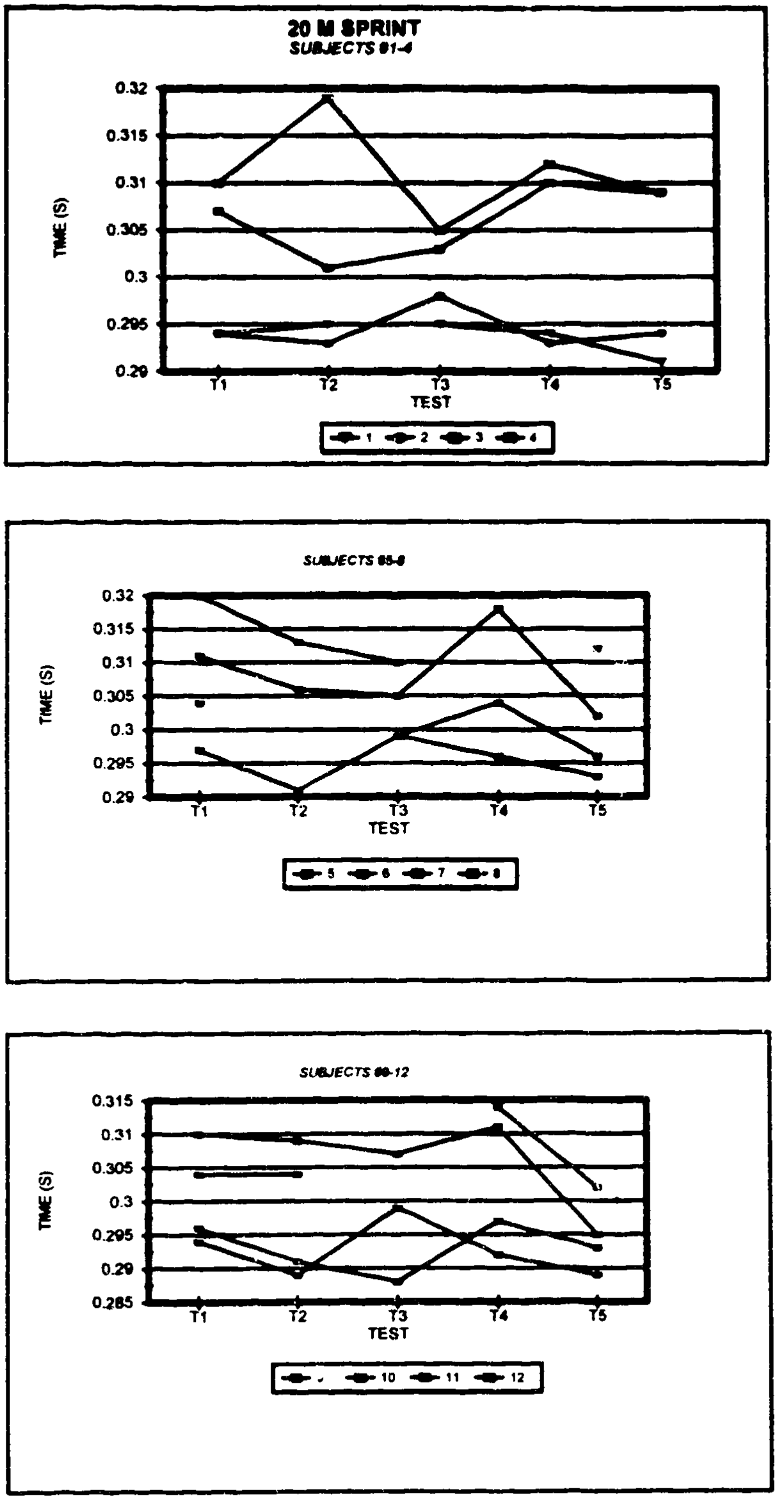
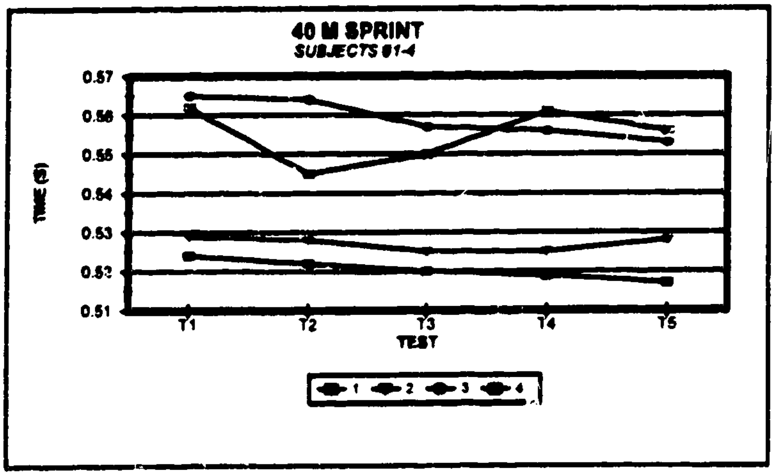
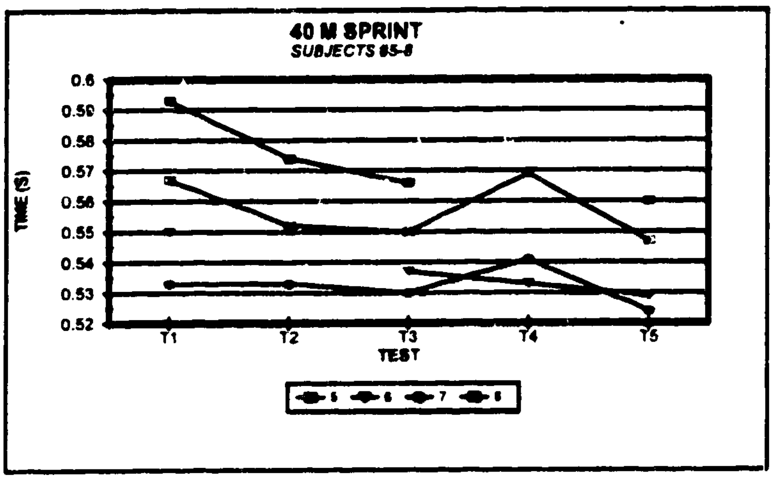
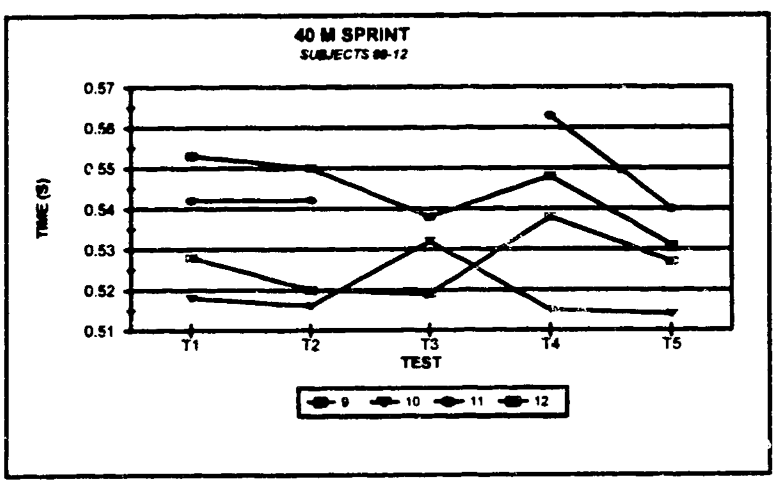


Figure 7: 40 m Sprint Scores Across 5 Tests







Subjective Evaluation of the Success of the Program

To assess the success of the plyometric program from the perspective of the athletes, a questionnaire was distributed and the results summarized in percentages. For the sake of presentation, the original five response categories of the Likert scale (stongly disagree, disagree, no opinion, agree, and strongly agree) were collapsed into three categories: disagree, no opinion, and agree.

The questionnaire was designed to gather information in the following areas: athletic performance, game performance, skill performance, effectiveness of the plyometric program, and factors in test performance. A summary of the results of the questionnaire can be found in Table 4. The questionnaire itself can be found in Appendix B.

Athletic Performance

As a result of the plyometric program, 75% (n=9) of the subjects felt faster, 67%(n=8) felt they could jump higher, and 66% (n=8) perceived themselves as being quicker. Half of the athletes felt they were stronger, had more endurance, or could maintain a higher level of intensity longer.

Game Performance

Fifty percent (n=6) of the subjects felt that plyometric training enhanced their game performance (42% (n=5) had no opinion). Sixty seven percent (n=8) of the athletes agreed that soreness due to plyometric exercises did not effect game performance. Unfortunately, despite training four days prior to competition, 25% (n=3) of the players felt that sometimes soreness did effect their game performance. Also, 75% (n=9) of the subjects felt that their practice performance was negatively effected by muscle soreness due to plyometrics.

Skill Performance

With the exception of defensive and rebounding ability there were no strong associations made between plyometric training and skill performance. However, 75% (n=9) of the athletes felt that their defensive ability improved due to the plyometrics, and 50% (n=6) felt that plyometrics had improved their rebounding ability.

TABLE 4: SUMMARY OF QUESTIONNAIRE

SUMMARY OF THE QUESTIONS	RESPONSE CATEGORY %* (n)					
	NR	1	2	3	4	5
1)Feel faster.	0	0	8(1)	17(2)	67(8)	8(1)
2)Feel I can jump higher.	0	0	0	33(4)	42(5)	25(3)
3)Feel quicker.	0	0	0	33(4)	58(7)	8(1)
4)Feel stronger.	0	0	8(1)	42(5)	42(5)	8(1)
5)Improved muscular endurance.	0	0	0	50(6)	33(4)	17(2)
6)Maintain higher level of intensity.	0	0	17(2)	33(4)	33(4)	17(2)
7)Enhanced game performance.	0	8(1)	0	42(5)	50(6)	0
8)Muscle soreness did not effect game performance.	0	8(1)	17(2)	8(1)	42(5)	25(3)
9)Muscle soreness didn't effect practice performance.	0	25(3)	50(6)	0	25(3)	0
10)Enhanced rebounding ability.	0	0	8(1)	42(5)	42(5)	8(1)
11)Enhanced penetration.	0	0	17(2)	50(6)	25(3)	8(1)
12)Enhanced defensive ability.	0	0	0	25(3)	67(8)	8(1)
13)Enhanced shot blocking ability.	0	8(1)	8(1)	50(6)	25(3)	8(1)
14)Enjoyed plyometric training.	0	0	0	17(2)	58(7)	25(3)
15)Effective speed & jump training.	0	0	0	8(1)	75(9)	17(2)
16)Training was sport specific.	0	8(1)	17(2)	8(1)	58(7)	8(1)
17)Instructions were clear & concise.	0	0	0	8(1)	42(5)	50(6)
18)Demonstrations were effective.	0	0	0	8(1)	50(6)	42(5)
19)Had a sufficient strength base.	0	0	8(1)	0	58(7)	33(4)
20)Strength program maintained base	0	0	0	17(2)	75(9)	8(1)
21)Plyometrics effective & efficient.	0	0	0	8(1)	50(6)	42(5)
22)Plyometrics too difficult.	0	25(3)	58(7)	17(2)	0	0
23)Muscle soreness confound tests.	0	0	0	58(7)	33(4)	8(1)
24)Plyometrics aggravate chronic inj	0	0	17(2)	25(3)	50(6)	8(1)
25)Muscle stiffness effect tests.	0	0	0	25(3)	50(6)	25(3)
26)Tests painful b/c chronic inj.	0	0	8(1)	17(2)	50(6)	25(3)
27)Motivation important test factor.	17(2)	0	17(2)	25(3)	42(5)	0

*NR=no response; 1=strongly disagree; 2=disagree; 3=no opinion; 4=agree; 5=strongly agree.

Effectiveness of the Plyometric Program

Eighty three percent (n=10) of the subjects in this study enjoyed the plyometric training, and 92% (n=11) felt that it was an effective and efficient mode of power training. However, as expected, 58% (n=7) felt that the plyometric exercises aggravated their chronic injuries.

Factors in Test Performance

Forty one percent (n=5) of the athletes felt that muscle soreness negatively effected their test performance. In addition, 75% (n=9) agreed that sometimes test performance was limited due to muscle stiffness. Seventy five percent (n=9) also agreed that testing was sometimes painful due to chronic injuries. Subjects did not seem to feel that motivation was an important factor in the testing.

Thus, it appeared that plyometric training had a substantial effect on the athletes' perceptions of their own athletic ability, making them feel faster, quicker, and that they could jump higher. Furthermore, muscle soreness from plyometric training did not appear to effect many players' game performance, although three players did feel that it affected their game performance (nine players felt it affected their practice performance). In fact, most of the athletes with an opinion felt that it actually enhanced their game performance, particularly their defensive and rebounding abilities. Finally, plyometrics appeared to be an enjoyable, effective, and efficient power training modality.

CHAPTER 5

DISCUSSION

Physical Characteristics

The average height, weight, and age of the subjects in this study was 191± 13 cm, 88.3 ± 20.2 kg, and 20.8 ± 2.8 years respectively. Siders, Bolonchuk, and Lukaski (1991), in a study on the effects of participation in a NCAA Division II men's basketball season on body composition, reported similar results, although their subjects were slightly taller. The average height, weight, and age of their team was 194 ± 7.2 cm, 87.5 ± 10.2 kg, and 20.9 ± 1.3 years, respectively.

Group Analyses

During the 14 week training period, subjects completed an average of 13 plyometric sessions, practiced approximately 5.5 hours per week, and completed the strength maintenance program an average of 13 and 7 times for upper and lower body, respectively. Given the various volumes of training one might question whether or not the results demonstrated in this study can be attributed soley to plyometrics. Of course it is always difficult to determine cause and effect, but it is possible to rule out, or at least, limit the effects of other training stimuli.

One might suggest that the results seen in this study are due to the training which took place within the basketball practices. Since a basketball practice includes repeated jumping, stopping, starting, and sprinting among other things, it is expected that there would be some improvement in power performance as a result. At what point this expected training effect would plateau, increase, or decrease is relatively unknown. In this case the three training groups entered the study at two week intervals following six weeks of basketball practice. This design was chosen to monitor the effects of basketball practice on power performance such that this effect might be controlled. Although there is a decrease in practice volume in the second half of the season, the intensity of practice generally increases. This decrease in volume and increase in intensity may have facilitated some increase in power performance between T3 and T5. Given the similarity of the pre-test results of groups two and three (Table 5) it might seem that there was a training effect in the eighth week of practice. However, in light of the different number of subjects within each group, and the small number of subjects overall, this conclusion must be considered cautiously. Indeed, examination of the group pre-test scores and the associated post-test scores suggests that the substantial pre-test difference noted between group #1 and groups #2&3 is due to divergent athletic ability between groups.

TABLE 5: PRE-POST MEANS OF THE TRAINING GROUPS

TRAINING GROUP	POWER TESTS					
	VJ-1 (cm)	VJ-5 (cm)	20m-1 (s)	20m-5 (s)	40m-1 (s)	40m-5 (s)
GROUP #1 (n=5)	59.9	62.1	3.08	3.04	5.61	5.44
GROUP #2 (n=4)	63	64.4	3.01	2.95	5.35	5.28
GROUP #3 (n=3)	62.3	65.2	2.99	2.96	5.40	5.31

Others might suggest that the significant results seen in this study are attributable to an increase in strength due to the weight training. It is unlikely that upper body strength training would have had such a significant effect on the VJ, 20, and 40 m sprints, since the training volume (less than once per week) was not great enough to have caused significant strength gain, if any. Although leg strength training was expected to have had an impact on the athlete's power performance, the training load was even less than that for the upper body; thus it is unlikely that it would have positively effected strength and consequently power. Some evidence exists which suggests that while strength can be maintained by weight training once per week it is unlikely that strength will improve (Graves et al, 1988). Therefore, since it is improbable that the upper body and leg strength of the subjects in the present study improved due to weight training over the training period, it is also improbable that the demonstrated increase in VJ and speed is due to strength training. It is possible, however, that power performance was negatively effected by a lack of strength training and consequently a loss of strength.

If the results of this study cannot be attributed to either basketball practices or the strength training, they must be a result of the plyometric training or, more likely, a combination thereof. The VJ results (an average increase in VJ of 2.1 cm) of the present study were not as pronounced as the results of some preceding research. Studies by Wilson et al (1993), Adams et al (1992), and Duke & BenEliyahu (1992) for example demonstrated average increases in VJ of 3.7, 3.8, 6.4 cm, respectively. It should be noted, however, that subjects in the present study could rarely train more than once per week because of their game schedule, while subjects in the forementioned studies trained 2-3 times per week. Furthermore, subjects in the forementioned studies were not elite althletes and as a result probably had more room for improvement than the athletes in the current study. Stated another way, the athletes in this study were closer to their biological ceiling than the subjects in the other studies.

Although no previous studies utilized the 40 m sprint, studies by Wilson et al (1993) and Polhemus (1981) did measure speed (30 m and 40 yard sprints, respectively). Contrary to the significant decreases noted in 20 m and 40 m sprint times (-0.05 s and -0.12 s, respectively) in the present study, subjects in the plyometric training groups of the forementioned studies did not show significant increases in speed. This result may have been due to the exclusive use of DJ in the plyometric training program. Hence the results of this study support the findings of other researchers, demonstrating that plyometric training can significantly ($p<0.05$) increase VJ and speed (Wilson et al, 1993; Adams et al, 1992; Duke & BenEliyahu, 1992; Brown, Mayhew, & Boleach, 1986; Clutch et al, 1983; Miller, 1982; Polhemus, 1981; Blattner & Noble, 1979).

A number of factors distinguish this study from preceding research. One factor which distinguishes this study is that the plyometric training was conducted, and the results evaluated, during a basketball season. Only one other study examined the effects of plyometric training within a collegiate sport season (Clutch et al, 1983). Their study compared the effects of weight, plyometric and volleyball training with weight and volleyball training. Although both groups achieved significant pre-post effects there was no significant difference between the two groups. It should also be noted that the weight training program utilized by Clutch et al (1983) had a sufficient load to elicit an increase in strength. Furthermore, no attempt was made to determine whether or not the plyometrics could be successfully incorporated in the overall training regime for the season. One limitation of their plyometric training program was that it consisted exclusively of depth jumps (DJ).

A second differentiating factor in the present study was that DJ's were not included in the plyometric training program. As previously indicated, the majority of the plyometric training programs in past research consist primarily of DJ (Wilson et al, 1993; Adams et al, 1992; Brown, Mayhew, & Boleach, 1986; Clutch et al, 1983; Miller, 1982; Polhemus, 1981; Blattner & Noble, 1979). As mentioned in the review of literature, a plyometric program should progress from lower to higher intensity exercises, and from general to more specific exercises. The plyometric program utilized in the present study was a progressive and well balanced program including a variety of plyometric exercises, excluding DJ.

Adams et al (1992) conducted a study comparing the effects of strength training, plyometric training, and strength and plyometric training on VJ. All three groups demonstrated significant improvement, but the group that combined strength and plyometric training improved their VJ almost three times more than the other two groups. Although their study was not conducted on elite athletes currently training for their sport, it does however, demonstrate the importance of the interaction between plyometric training and other forms of power training. It seems that this interaction was also apparent in the present study, suggesting that plyometric training complements traditional modes of power training (ie., strength training) such that even greater results can be achieved. It appears that plyometric training does indeed bridge the gap between strength training and power (Lundin & Berg, 1991; Lombardi, 1989; Yessis, 1989; McFarlane, 1985; Chu, 1983; Mann, 1981).

Given the limitations of alternative hypotheses, the results of this study demonstrate that plyometric training assists in the development of power in athletes currently training for their sport. Furthermore, it appears that a progressive, well balanced plyometric program, excluding DJ, can also help to significantly improve VJ performance and speed.

Individual Analyses

A multiple baseline across subjects quasi experimental design was employed in this study, and consequently each subject served as his own control (ie., there was no control or comparison group). An advantage of the single subject design is the ability to examine each subject and his/her situation individually. In the interest of simplicity and readability the discussion on the individual results will be presented one subject at a time, to be followed by conclusions regarding common trends in the data and the success of the program. A summary of the individual data is presented in Table 3 and Figures 1-4.

Subject #1

Subject #1 was a 22 year old 178 cm, 68.1 kg point guard who averaged over 20 minutes (min) playing time per game. He completed 13 plyometric sessions and was a good trainer who enjoyed the program but may not have given himself enough rest between sets, and as a result may not have benefitted as much as he could have. This athlete also struggled with weight training and as a result rarely completed the strength maintenance program (weight trained approximately 2 times per month). This athlete was also troubled with illness towards the end of the training period. Consequently, subject #1's results were less than average. His VJ improved 1.2 cm , and his 20 and 40m sprint times decreased -0.03 and -0.07 s, respectively.

His VJ peaked at Test 3 (T3) demonstrating an improvement of 2.7 cm at that point, after which there was a steady decline in VJ performance. This decline may have been caused by several factors. One reason may be the absence of strength maintenance, and perhaps a strength decrease over the course of the training period which would negatively effect the plyometric training. Furthermore, as a result of the illness this subject experienced toward the end of the training period, his playing time was reduced, and his training intensity also suffered.

Subject #1's sprint times do not follow the same pattern as his VJ scores. Rather, both the 20 m and 40 m sprints showed steady improvement, with the greatest improvement shown between T4 and T5. The reason for the difference in performance patterns between the sprints and the VJ tests remains unclear, although it may in part be due to the type of sprinting which takes place during basketball practice and games.

Subject #2

Subject #2 was a 21 year old 196 cm, 90.8 kg forward who rarely played in games. He completed 14 plyometric sessions and trained very hard. Subject #2 completed the upper and lower body weight program 19 and 6 times respectively during the 14 week training period.

His VJ improved 3.7 cm after 14 weeks of training. He reached his peak after just four weeks of training showing an improvement in VJ of 4.5 cm. This significant increase early in the program may have been a result of consistent leg weight training in conjunction with the plyometrics. However, although the change was not as dramatic, between T3 and T5 he also demonstrated consistent improvement despite the lack of leg weight training during the last 7 weeks of the study.

The tremendous increase in VJ performance was not paralleled by an improvement in sprint performance, in fact the plyometric training seemed to have no effect at all on this athlete's speed (no change in 20 m sprint time and only -0.01s in the 40 m sprint). He seemed to have peaked early in the training program and then tapered off. This tapering may be a result of the lack of leg strength training during the latter portion of the study. This decrease in performance may also reflect the general decrease in playing time this athlete experienced during the latter half of the season.

Subject #3

Subject #3 was a 20 year old 196 cm, 113.5 kg forward who averaged over 20 minutes per game. He completed 13 plyometric sessions and was a very serious trainer with an exceptional work ethic. Subject #3 was the only athlete whose BMI was higher than recommended, and this was probably due to the muscularity of this subject. Given the size of this athlete he was instructed to place more emphasis on the acceleration phase of a given exercise than the deceleration phase. Perhaps these instructions should only have been given for the more difficult and specific exercises introduced in the latter stages of the program. This athlete performed upper body weight training 13 times, and leg strength training 4 times. Although this subject was very strong, perhaps the lack of leg strength training during the latter stages of the training period (Nov. 29 - Jan. 31) negatively affected his response to plyometric training. He also suffered from patellar tendinitis which may have hindered his training as well as his performance on the VJ and 20 m sprint tests.

Subject #3 actually experienced a decrease of 1.2 cm in VJ performance over the training period. He was the only athlete out of the whole group who experienced a negative effect. Interestingly, he suggests in the questionnaire that he felt he could jump higher a result of the plyometric training. The decrease in VJ may be due to the previously mentioned lack of leg strength training, but more likely is due to increasing knee soreness as a result of tendinitis. Incidently, it was the development of the tendinitis which precipitated the cessation of leg strength training. The generally steady decline in VJ performance demonstrated by the athlete suggests that as the tendinitis grew progressively worse there was a parallel decline in VJ performance, due to interference with both weight and plyometric training, or as a result of pain - which may have been brought on by extra training. In the questionnaire, this athlete agreed that testing was sometimes painful because of his chronic injuries.

His 20 m sprint times showed very little change (-0.01s) from pre- to post-test, although within the training period there was substantial change. Subject #3 peaked at T3 with a decrease in sprint time of -0.05 s. At no point was there a steady increase or decrease. On the other hand, his 40 m sprint performance improved steadily and significantly demonstrating an improvement of -0.12 s. Perhaps leg strength has more of an effect on shorter duration power events such as the VJ and 20 m sprint than longer duration power events such as the 40 m sprint. It may also be that the tendinitis played more of an inhibitory role on the rapid powerful contractions seen in the VJ and acceleration phase of the 20m sprint. Subject #3 showed greatest improvement in sprint times between T2 and T3, incidently the same time period during which leg weight training was terminated. One might hypothesize that leg strength had been built to an optimal level and then was tapered off prior to T3 resulting in peak performance testing.

Subject #4

Subject #4 was a 18 year old 183 cm , 74.9 kg point guard who practiced but did not play in league games this year, and as such played very little, and only in the preseason. Furthermore, because he was a "red shirt" he received less and less time in practice as the season progressed. He was a good trainer although he may have lacked the desired intensity at times. He completed 14 plyometric sessions during the 14 week training period. This athlete completed the upper and lower body strength training program 14 and 12 times respectively. Subject #4 was quite sick during the Christmas break, and in addition did not travel to the Christmas tournament. As a result he missed a lot of practices and training during this period (Dec. 20 - Dec. 27).

Subject #4's VJ improved 2.4 cm from pre- to post-test. He peaked at T5 although his difference score at T3 was virtually the same (2.2 cm). His VJ performance decreased at T4, probably because this was his first week back in training following the Christmas break and his illness.

Subject #4's 20 m sprint performance declined over the course of the study, demonstrating an increase of +0.02 s. His 20 m sprint times peaked at T2 with a decrease in time of -0.06 s. From that point his speed declined, with the greatest negative effect shown between T3 and T4. Similarly, although there was an overall improvement in his 40 m sprint times of -0.06 s, there was a substantial decline in performance between T3 and T4 (+0.11 s) from which he never fully recovered.

Across all three power performance tests there is a trend of decreased performance between T3 and T4. The most obvious explanation for this phenomenon is the Christmas layoff and the illness experienced by subject #4 during this time period. Having been off for so long (nearly three weeks) with no training and a poor diet due to his inability to keep food down, he seemed to have lost the training effect evidenced in T3. Furthermore, due to his eagerness to gain back what he had lost, he went from doing no leg weights from Dec. 13 - 27 to doing leg weights 3x/week Jan. 3 - 24. This extra training so soon after his illness and layoff may have been too much for his system to handle, resulting in a reduction in performance at T4. Another possible explanation is that the introduction of squat jumps during this period may have caused unusual muscle soreness on the testing day, thus inhibiting the testing. Subject #4 agreed that muscle soreness was a confounding factor in test performance.

Subject #5

Subject #5 was a 20 year old 188 cm, 79.5 kg off guard who averaged well over 20 minutes per game. He completed 12 plyometric sessions and was a good trainer interested in improving his athletic ability. He missed several training sessions and T4 due to an ankle injury (Jan.10 - 24). This athlete also struggled with consistency of weight training completing only 7 sessions for both upper and lower body. He did no upper body strength training between Dec. 20 and Jan. 10 and no leg weights between Dec. 20 and Jan. 31 (between T3 and T5).

Subject #5's VJ increased 5 cm as a result of the plyometric training. The greatest gain (5 cm) was seen between T2 and T3 after which there was slight improvement to T5 (assuming there was a linear trend through T4 for which we have no data due to injury).

This athlete's sprint performance follows a similar pattern. His 20 and 40 m sprints improved by -0.08 and -0.33 s respectively. Again, the greatest gains were made between T1 and T3, after which gains tapered off or were even lost (as in the 20 m sprint). During the first two months of training Subject #5's 20 m sprint times improved by -0.10 s. During the same time period his 40 m sprint time improved by -0.27 s.

Although this athlete demonstrated the greatest improvement out of this group of athletes one might speculate as to why his performance tapered off during the latter stages of the training period. There are several plausible explanations for this trend in the data (bearing in mind that the data for T4 is missing). As mentioned earlier subject #5 missed 3 plyometric sessions between T4 and T5 due to an ankle injury. This lack of training may have caused the tapering of the training effect. Furthermore, as mentioned in the discussion of other subjects, there appears to be some relationship between the cessation of weight training and performance. Note that subject #5 ceased leg strength training the week of Dec. 13, the same week as T3, after which the rate of improvement diminished considerably. Other factors which may have come into play in this athlete's results is a reduction in both team and individual practice during the last six weeks of the plyometric training program. On another note, one might ask why did this athlete improve so much compared to the others? Perhaps it is because this athlete had more potential for improvement. This question will be a addressed in the conclusions of the discussion.

Subject #6

Subject #6 was a 22 year old 191 cm, 86.3 kg off guard who averaged less than 20 minutes per game, but received consistent playing time. Due to an ankle injury Nov.15 he completed only 9 plyometric sessions, the majority of which took place from Dec. 13 to completion. As a consequence of the ankle injury he also missed T2. This subject was a very good trainer who concentrated not only on intensity but on technique. He weight trained 7 times for both upper and lower body, but did not strength train between Dec. 27 and Jan. 17. Despite missing the 4 plyometric session between Nov. 15 and Dec. 6, he still obtained good results.

Subject #6's VJ improved 2.8 cm. There was a decline in VJ performance between T1 and T3 (data for T2 was unavailable) followed by a steady and rapid increase to T5.

Subject #6 demonstrated near linear improvement of his speed, improving his 20 and 40 m sprint times by -0.11 and -0.21 s respectively. Because data for T2 was missing, it is difficult to determine the effect of the ankle injury on this subject's speed.

Despite missing 4 plyometric sessions (and T2) between T1 and T3 due to an ankle injury, subject #6's VJ and speed improved substantially. Reasons for this phenomenon remain unclear, however despite the ankle injury subject #6 continued to practice (missing only one practice during the injury period) and to weight train. This may have counteracted the possible negative effect of missed plyometric training. Since there is no data for T2 it is difficult to surmise whether or not the layoff had a temporary effect on his VJ or speed.

Subject #7

Subject #7 was a 22 year old, 191 cm, 93.1 kg forward who averaged less than 20 minutes per game, but received consistent time throughout the season as the sixth man. He was the only subject to successfully complete all 15 plyometric sessions within the 14 week training period. He was a good trainer although his training was affected to some degree by tendinitis in his shoulder. Similarly he was often unable to do upper body weights and as a result completed only 6 sessions. Unfortunately, he also let his leg strength training slide, completing only 6 leg weight sessions. The only deabilitating injury he experienced was prior to the final week of testing, and as a result had to be tested one week later.

Subject #7's VJ improved 2.2 cm as a result of the plyometric training, although he peaked at T3 (3.7 cm). T4 demonstrated quite a decline in VJ performance from which he never fully recovered.

Subject #7's sprint performance followed a similar pattern at T4 with substantial decrease in speed (+0.07 and +0.08 s for the 20 and 40 m sprints respectively). Despite the significant loss of speed demonstrated in the third month of the study, he improved in the last two weeks of training, and ended with increases in speed of -0.01 and -0.09 s (20 m and 40 m sprints respectively). In fact between T4 and T5 (which was one week later than scheduled due to injury) subject #7 improved his 40 m sprint time -0.17 s.

There may be several explanations for the decrease in performance seen in T4. As demonstrated in other subjects there may have been a loss of training effect over the Christmas break. Compounding the problem of the Christmas layoff, subject #7 was sick between Dec. 29 and Jan. 3. Another possible explanation was the reduction of individual and team practice time during the period between T3 and T4. Also, as demonstrated in other subjects, there seems to have been a negative training effect due to the cessation of weight training during this time period. Finally, the introduction of squat jumps into the training program may have caused unusual muscle soreness which in turn inhibited performance, although in the questionnaire subject #7 had no opinion as to whether or not muscle soreness or stiffness effected testing.

Given the substantial improvement noted between T4 and T5, particularly in the sprints, some attempt at explanation must be made. The most obvious explanation is that subject #7 had one week off training prior to testing, and as such was fully rested and recovered for optimal performance on the tests. However, this same effect was not seen in subject #5 or subject #6 who also missed training due to injury prior to the test. Another plausible explanation is that between T4 and T5 he began weight training again, training for two weeks and then taking a week off for injury prior to testing. It is doubtful, however, that two weight training sessions would make such a substantial difference after a 5 week layoff. The most plausible explanation for the apparently improved performance noted at T5 is that subject #7 simply had a bad testing day at T4.

Subject #8

Subject #8 was a 21 year old, 196 cm, 90.8 kg forward who played less than 10 minutes per game. He completed 13 plyometric sessions, and although at times he lacked concentration, he was a fairly good trainer. This subject was one of the most consistent weight trainers, completing 17 sessions for both upper and lower body respectively.

Subject #8's VJ improved 3.8 cm, second only to subject #5. The improvement, however, was less than steady. Most noticeable is a large drop in VJ ability between T3 and T4 (-9 cm) from which he did not fully recover to the peak he experienced at T3 (5.8 cm).

Although they do not peak until T5, his sprint times follow a similar pattern, demonstrating a large decrease in speed between T3 and T4. Nonetheless subject #8's 20 and 40 m sprints peak at T5 with respective post-test times -0.09 and -0.20 s faster than the pre-test scores.

Given the common trend between all three power tests one must wonder what caused such poor performance on T4. Several explanations are feasible. First is the lack of weight training between T2 and T4. He ceased doing any weight training until two weeks prior to T4, at which point he began strength training 2x/week. This increased training load may have elicited muscle soreness and perhaps fatigue prior to T4. Furthermore, he weight trained twice during the week of testing which may have interfered with the test results. During the week of T4 subject #8 did in fact report feeling tired and sore. Thus, the lack of weight training in the weeks prior to T4 may have caused the decrease in performance, or the increased volume of training the two weeks preceding T4 may have inhibited performance on the power tests. Soreness from the weight training may have been further exacerbated by the introduction of squat jumps to the plyometric program. While subject #8 had no opinion regarding the effect of muscle soreness on test performance, he did agree that muscle stiffness sometimes limited his test performance. Another possibility is that subject #8's playing time was reduced to almost zero after T3. However, if this were the major factor responsible for the poor results in T4 one might expect similar results in T5 since his playing time was not increased between T4 and T5.

Subject #9

Subject #9 was a 21 year old 201 cm, 102.2 kg centre, who averaged well over 20 min per game as a starter. He completed 14 plyometric sessions and was a good trainer, although patellar tendinitis may have had a negative effect on both his training and testing. This athlete also had difficulty completing the strength maintenance program. He completed 6 upper body strength training sessions and only 3 sessions of leg strength training within the duration of the study (the last leg training session was Nov. 22).

Subject #9's VJ improved 1.9 cm, although he peaked at T2 with an increased VJ of 3.2 cm. T3 saw a 2.5 cm drop in performance followed by a steady increase to T5. One possible reason for the drop in performance between T2 and T3 was the lack of games and therefore playing time during this period. Similarly team practice time was reduced and there was no consistent individual practice time to make up for it. Furthermore, it may be that the lack of lower body weight training from Nov. 22 may have had a negative effect on T3. It could be argued that if this were the case why did the downward trend not continue from T3 to T5? While this effect was not seen, there was, however, a slower rate of improvement between T3 and T5 than there was between T1 and T2.

Subject #9's 20 m sprint time improved substantially dropping -0.15 s. His 40 m sprint time also improved significantly (-0.22 s). Both the 20 and 40 m sprints showed reasonably steady improvement until T4 at which point sprint times showed increases of +0.04 and +0.10 s respectively. Why T4 displays such poor sprinting results while the VJ showed a slight increase is difficult to understand. One possibility is that the back problems subject #9 was experiencing around the time of T4 had more of an inhibitory effect on sprint performance. A second possibility also related to injury is that the patellar tendinitis was also active at T4, and that it too had an inhibitory effect on the sprints. However, this possible inhibitory effect of the tendinitis was not seen in T5 despite reports of knee soreness during the final week of testing. Nonetheless subject #9 did agree that testing was sometimes painful due to chronic injuries. A related explanation is that these injuries placed constraints on the training efficiency of this subject. As seen in other subjects the muscle soreness caused by the introduction of squat jumps into the plyometric training program may have inhibited power performance at T4. Subject #9 felt strongly that muscle soreness was a confounding factor in test performance.

Subject #10

Subject #10 was the only black athlete in the study. He was a 22 year old, 188 cm, 85.8 kg forward who averaged over 20 minutes per game. He would probably be described as the best athlete in the group, although he was hampered this season by chronic knee problems. This athlete completed 14 plyometric sessions and was a good trainer, albeit at times his training and testing was hindered by the chronic knee injury (strong agreement is noted in his questionnaire). Subject #10 completed the upper body strength training program 20 times, but rarely trained his legs because it caused too much pain.

Subject #10's VJ improved 0.9 cm. During the first 2 months of plyometric training this athlete's VJ performance dropped 3.8 cm, but recovered 4.7 cm in the last 6 weeks of training allowing him to peak at T5.

His sprint times also improved although the improvement in the 40 m sprint was not very substantial (only -0.04 s). On the other hand the improvement in 20 m sprint time was significant, demonstrating a decrease of -0.05 s. Similar to the results of the VJ testing, the sprint times did not improve at a steady rate. Rather, there was a dramatic decrease in performance at T3, followed by improved performance in the last 6 weeks of training.

It is difficult to ascertain the cause of the serious decline at T3, but one possibility is the two week Christmas layoff just prior to T3. There may also have been exceptional knee soreness on the testing day due to the return to training after the break. As far as the relatively poor results overall are concerned, there are two likely explanations. The first and most likely is the inhibitory effect of the knee problems on testing. This effect was especially noticeable in the sprints, particularly in the last 20 m of the 40 m sprint, where the athlete could often be seen limping. This may explain why the results for the 20 m sprint are superior to the results for the 40 m sprint. Another plausible explanation is the lack of leg strength training throughout the training period. It is likely that there was a progressive loss of leg strength throughout the study which may have interfered, to some extent, with the potential gains achieved through plyometric training. Furthermore, since subject #10 was one of the fastest sprinters and had the highest VJ, perhaps he had less room for improvement than the other subjects.

Subject #11

Subject #11 was a 20 year old, 193 cm, 89.4 kg off guard who played more than ten minutes per game. He completed only 9 plyometric sessions and missed T3 due to shin splints. He worked hard but was an awkward trainer and had difficulty learning the exercises. This athlete was a proponent of weight training but because of the shin splints rarely did leg weights completing 26 and 4 sessions of upper and lower body weights respectively.

Subject #11's VJ improved 1.5 cm during the 14 week training period. He peaked at T2 with an increase in VJ of 2.7 cm, after which there was a steady decline in performance until T4. From T4 to T5 this subject demonstrated a slight increase in performance.

Subject #11's 20 and 40 m sprint performance improved only slightly demonstrating a decrease in time of -0.02 s for both sprints. The pattern for the 20 and 40 m sprints is similar. There was no change between T1 and T2, but similar to VJ there was a substantial decline in performance between T2 and T4. Unlike the VJ, however, the sprint times showed substantial improvement during the last 2 weeks of training.

Given the similar pattern between all three power tests, it may be asked why there was such a dramatic decrease in performance between T2 and T4. Because the data for T3 is missing it is difficult to determine whether or not there was a negative trend in performance between T2 and T4 or if T4 was simply a poor test. Subject #11 completed only 2 plyometric sessions between T2 and T3, and they were done in the same week. He completed three plyometric sessions just prior to T4 after nearly a month off. Given the erratic nature of this subject's participation in the plyometric program it is likely that he never made the progressions the other athletes did and as a result experienced a lot of muscle soreness every time he did plyometrics. This soreness most likely effected his test performance at T4, in addition to a loss of training effect over the Christmas lay-off. Subject #11 agreed that his test performance was sometimes effected by muscle soreness, and felt strongly that his test performance was sometimes effected by muscle stiffness. He also agreed that testing was sometimes painful because of chronic injuries, which may also have negatively effected his performance.

Subject #12

Subject #12 was a 21 year old, 191 cm, 88.3 kg forward who averaged far less than 10 minutes per game. He completed 14 plyometric sessions and was a very good trainer. He completed the upper body strength training program 11 times, including three weeks off during the Christmas break. He completed the leg strength training program 8 times - the last session being Jan. 10.

Subject #12's VJ improved 1.5 cm. His scores at T3 and T5 were the same with a decrease in performance at T4. This athlete's 20 m sprint time improved -0.03 s, and his 40 m sprint time improved -0.01 s. Despite the results, subject #12 felt faster and quicker as result of the plyometric training. Both the 20 m and 40 m sprints peaked at T3 with respective times -0.08 and -0.09 s less than the pre-test measure. All three power measures demonstrated a similar pattern showing a relatively steady increase to T3, a decline in performance at T4, and some recovery at T5.

One possible explanation for this trend in the data may be the virtual cessation of leg strength training just prior to T3. This in combination with the Christmas layoff may have had a negative effect on performance. Furthermore, although this athlete received more game time over the Christmas break, there was less practice time so his over all training volume was reduced during this period. Another plausible explanation for this trend is the introduction of squat jumps into the training program between T3 and T4. This exercise causes a great deal of muscle soreness which may have inhibited test performance. Subject #12 agreed that sometimes muscle soreness was a confounding factor in test performance.

Conclusions Drawn From Individual Analyses

Several conclusions can be drawn from the information gleaned in the individual analyses regarding the effects of plyometric training on power performance. First and foremost is the apparent relationship between strength and benefits of plyometric training. Unfortunately strength gains or losses were not monitored in this study. However, there appears to be a relationship between the cessation of the strength maintenance program and a decrease in performance of the power tests. This effect is apparent in 9 of 12 subjects to one degree or another. This effect was not seen consistently across tests. For example in some cases it appeared to have more of an effect on the performance of the shorter duration VJ and 20 m sprint tests (ie., subject #3). Furthermore, some subjects did not show a loss in performance, but rather a reduction in the rate of improvement (ie., subject #9). Other subjects began weight training heavily after an extended layoff, most likely causing fatigue and soreness which may have hindered the power testing (ie., subject #4).

A second factor which clearly influenced the effect of plyometric training was the Christmas layoff. Several athletes suffered a decline in performance following Christmas. It appears that the lack of training (and perhaps over-eating) over this time period negatively affected the performance of the VJ, 20, and 40 m sprints. For two athletes this negative effect was compounded by illness (ie., subject #4 and #7). This temporary illness induced a reduction in both the volume and intensity of training.

Chronic injuries such as tendinitis also seemed to have a negative effect on power performance over the course of the study. Note that 9 out of 12 subjects agreed that testing was sometimes painful because of chronic injuries. Several of the athletes in this study suffered from patellar tendinitis, and although they may have achieved good results overall there definitely seemed to be a negative effect on performance (ie., for some athletes some tests were more affected than others). For example, subject #3's VJ and 20 m sprint tests were seemingly more influenced by his tendinitis than the 40 m sprint. Perhaps due to the size of this athlete the powerful contractions necessary for maximal VJ and acceleration in the 20 m sprint caused too much pain, thus hindering the results. On the other hand for two other athletes (subjects #9 and #10) tendinitis seemed to have more of an interference effect on their sprints than their VJ tests. Subject #10 could even be seen limping during the 40 m sprints. Conceivably it was a combination of size, weight, body mechanics, and tendinitis which seemd to negatively effect power performance.

A fourth factor which may have influenced test results at T4 was the introduction of squat jumps to the program. Squat jumps were introduced differentially by groups at some point between T3 and T4. Squat jumps are a plyometric exercise which do not allow the assistance of arm motion and require substantial range of motion relative to other plyometric activities. As a result they caused a great degree of muscle soreness which lasted up to four days. Since athletes trained on Mondays, and testing was usually on Wednesdays, it stands to reason that athletes would still be quite sore on the testing day. While this may not have effected training it most certainly may have effected test performance. In fact 41% of the subjects felt that muscle soreness was a confounding factor in test performance, and 75% felt that sometimes test performance was limited because their muscles were too stiff.

As mentioned in the discussion on subject #5, one factor which effected athletes' responses to plyometric training was their potential for improvement. Assuming that those athletes who achieved poorer results on the pretests had more potential to improve than those athletes who did well on the pretests, one might hypothesize that the poorer athletes would improve more. By examining the mean differences between the top and bottom three athletes' difference scores one can see that there is some merit to this theory. The three poorer athletes improved their scores more than their athletic counterparts by an average of 0.94 cm, -0.08 s, and -0.177 s for VJ, 20 m and 40 m sprints respectively. Obviously there was a significant difference in improvement between these two groups.

Three subjects missed substantial plyometric training sessions (3, 6, and 6 for subjects #5, 6, and 11 respectively) and one test due to injury. Subjects #5 and 6 seemed to have been affected to a small degree, as evidenced by small decreases in performance or a reduction in the rate of improvement. Contrarily, subject #11, who struggled with shin splints throughout the training period missed 6 plyometric sessions and as a result achieved results far less than the average.

A seventh factor which seemed to have some influence on the results was a decrease in game time. Both subject #2 and 8 experienced a decline in performance following a decrease in playing time. The effect is particularly evident in the case of subject #8. Again, this suggests an interaction between plyometric training and other training stimuli within a basketball season.

One final element which seems to have influenced the effects of plyometric training was the instructions given to the heavier athletes. Athletes who weighed in excess of 91 kg were instructed to place more emphasis on the acceleration phase than the deceleration phase of the plyometric exercises. Seemingly subject #3 was most affected by this factor. In hind sight, perhaps this emphasis should only have been given during the more intense and specific latter stages of plyometric training. This may have allowed the athlete to train at a more appropriate intensity without a greater risk of injury.

It should be noted that it is unlikely that a decrease in performance can be attributed solely to any one of the above factors, rather performance is more likely negatively affected by a combination of factors. Furthermore, as previously mentioned, results and interpretations made were not always applicable across all five tests. On a different note, in several cases observed performance data did not demonstrate significant improvement, however, as a result of the plyometric training the athletes felt subjectively faster, quicker, or that they could jump higher. One should not underestimate the effect this superior confidence might have on performance on the whole, and the edge it might give an athlete over his competitors.

CHAPTER 6

CONCLUSIONS

Rationale

Given the increasingly competitive nature of sport at higher levels, coaches and athletes alike are searching for methods of training which will give them a performance advantage. Plyometrics is a form of power training involving maximal muscular contractions in response to rapid stretching of the muscles used in the contraction. Many exercise practitioners and researchers believe that plyometric training is one important answer to the problem of how to improve power performance (Bompa, 1993; Wilson et al, 1993; Adams et al, 1992; Chu, 1992; Duke & BenEliyahu, 1992; Javorek, 1989; Bielek et al, 1986a; Brown, Mayhew, & Boleach, 1986; Adams, 1985; Radcliffe & Farentinos, 1985; Clutch et al, 1983; Miller, 1982; Polhemus, 1981; Blattner & Noble, 1979).

Unfortunately past research on plyometrics is insufficient. Given the problems with the plyometric programs in past training studies and the lack of applied research, an attempt was made to determine whether or not a properly designed plyometric training program would enhance power performance (as operationalized by VJ, 20m and 40m sprints) over and above any improvements which may be seen as a result of regular participation in normal sport specific training throughout a season.

Methods

Participants were drawn from the University of Alberta's mens basketball team, providing a sample of 12 university males. Subjects were assigned to one of three groups, and each group entered the study at 2 week intervals. Each subject served as his own control. Performance on VJ, 20 m, and 40 m sprints were pre- and post-tested in addition to three repeated measures within the 14 week training period. Furthermore a questionnaire was administered to determine subjectively whether athletes felt plyometrics could be successfully implemented within the context of a basketball season.

Results

The average height, weight, and age of the subjects was 191 cm, 88.3 kg, and 20.8 years, respectively. One of the twelve subjects was Black, the remaining 11 subjects were Caucasian. An average of 13 plyometric sessions were completed over the 14 week training period.

The average VJ of the subjects in this study significantly improved 2.14 cm ($p<0.05$). Athletes' 20 m sprint times also improved significantly ($p<0.05$) demonstrating a mean decrease in sprint times of -0.047 s. Similarly, the 40 m sprint times of the athletes improved by -0.115 s, a significant increase in speed ($p<0.05$). Therefore, given the limitations of alternative hypotheses, the results of this study demonstrate that plyometric training assists in the development of power in athletes currently training for their sport.

The results of the questionnaire suggest that this plyometric training program was successfully included within the season's training regime. The majority of the subjects in the study felt that their athletic and skill performance were enhanced. Athletes found the training to be enjoyable, effective, and efficient. Furthermore, regardless of the observed results, many of the athletes felt that they were faster, quicker, or could jump higher as a result of the plyometric training. One should not underestimate the effect this new found confidence might have on an athletes' performance.

Individual analyses revealed a number of factors which may have influenced the results of the study. For example, there appears to be a connection between strength training and plyometric training. In several cases there appeared to be a negative relationship between the cessation of strength maintenance and the results from plyometric training. Another factor which influenced the training effects was the Christmas layoff. It would seem that the lack of training associated with this time period had a substantial effect on power performance. One factor which appeared to have a negative effect on testing, and perhaps the quality of training, was chronic injury. And finally, athletes with seemingly the most potential to improve did demonstrate greater improvement than their apparently more athletic counterparts.

Recommendations for Future Research

There are problems associated with doing controlled work in real situations such as performance variability of subjects and environmental variability. Despite these problems, quasi-experimental research conducted in real situations is important, and applicable to exercise practitioners and coaches.

Given the results of this study and the information gleaned from the individual analyses several recommendations for future research come to the fore. First, in regards to the relationship between strength and plyometrics, two suggestions must be made: one, that there is more strict control over participation in the strength maintenance program, and two, to measure strength regularly throughout the study. Objective measures of strength and performance variables might give some insight into possible interactions between strength and effects gained from plyometric training. Furthermore, one could alter the strength training program across groups while maintaining the same plyometric program to determine what combination is most effective at enhancing power. For example, subjects could be divided into four groups: strength training only, plyometrics only, strength and plyometric training, and a control group.

A second recommendation is to introduce plyometric training earlier in the training calendar. It would be interesting to determine the effects of a long term power training program including plyometrics. For example, the first phase of the study would involve 2 months of strength training, followed by the introduction of plyometrics and reduced strength training. In the third phase, the competitive season, the volume of strength training and plyometrics would be reduced to maintenance with appropriate tapering surrounding competitions. It is this type of applied power training research that is required by coaches and exercise practitioners alike.

A third suggestion is to monitor the effects of plyometric training on chronic injuries. Frequent assessment using a pain scale in addition to an interview might provide useful information on how to train with plyometrics despite chronic injuries.

Another suggestion for future research is to examine the apparent psychological benefits which may occur as a result of plyometric training. For example, several athetes in this study felt that they were faster, or could jump higher as a result of the plyometric training, despite poor performance measures. It would be interesting to discover if there is a link between these perceived gains in athletic performance and performance in game situations.

Finally, there is a need for more applied research which will help coaches utilize plyometric training more effectively in their seasonal training regimes. Research which addresses the feasability of plyometric training within a season is difficult to find but may be of the most use to a coach; for it is this type of research which contains information on how to successfully design or adapt a plyometric program to his/her team and circumstances.

Conclusion

In conclusion, the increased power performance demonstrated in this study appears to be due to a complex combination of basketball practice, strength training, and plyometric training. Therefore, it was concluded that plyometric training assists in the development of power performance, and can be successfully incorporated into a basketball training regime. Perhaps it is no coincidence that in the first season that plyometrics were utilized by this basketball team, they also won their first national championship.

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APPENDIX A

PLYOMETRIC TRAINING PROGRAM

PLYOMETRIC TRAINING SESSION #1 and #2

2 Foot Ankle Hop *(3x10)*
-Feet shoulder-width apart, using ankles only hop continuously in one place.
-Extend ankles fully on each vertical hop.
-Chu recommends this exercise for all beginners to perfect technique.

Rim Jumps *(4x10)*
-Feet shoulder width apart under a high object.
-Jump continuously, reaching with alternating hands trying to reach the object.
-Time on the ground should be minimal. Effort maximal.

Front Cone Hops *(4x8)*
-Row of 8 cones, 4 ft. apart.
-Keep feet shoulder width apart jumping over each cone, landing with both feet at the same time.
-Use a double arm swing and work to decrease the time spent on the ground between each cone.

Side Hop *(3x8)*
-Place two cones (18-26") 2-3 ft. apart.
-Start outside one of the cones with feet together and arms cocked ready to provide lift.
-Jump sideways over the two cones and without hesitation change direction and jump back over the cones; continue this back-and-forth sequence.
-Use arms for upward thrust; thumbs up, elbows 90'.

PLYOMETRIC TRAINING SESSION #3 and #4

2 Foot Ankle Hop (3x10)
-Feet shoulder-width apart, using ankles only hop continuously in one place.
-Extend ankles fully on each vertical hop.
-Chu recommends this excrcise for all beginners to perfect technique.

Rim Jumps (4x10)
-Feet shoulder width apart under a high object.
-Jump continuously, reaching with alternating hands trying to reach the object.
-Time on the ground should be minimal. Effort maximal.

Front Cone Hops (5x8)
-Row of 8 cones, 5 ft. apart.
-Keep feet shoulder width apart jumping over each cone, landing with both feet at the same time.
-Use a double arm swing and work to decrease the time spent on the ground between each cone.

Side Hop (4x8)
-Place two cones (18-26") 2-3 ft. apart.
-Start outside one of the cones with feet together and arms cocked ready to provide lift.
-Jump sideways over the two cones and without hesitation change direction and jump back over the cones; continue this back-and-forth sequence.
-Use arms for upward thrust; thumbs up, elbows 90'.

PLYOMETRIC TRAINING SESSION #5 and #6

Skipping (4x30m)
-Upright position, one leg slightly ahead of the other.
-Drive off the back leg, initiate a short skipping step, thrust the opposite knee hard and fast up to chest level.
-Upon landing repeat the pattern with the opposite leg.
-Thus the pattern is: *right-right-step-left-left-step-right-right.*
-Max. hang-time, minimal ground time.

Double Leg Speed Hop (3x8)
-Back straight, head up, shoulders slightly forward, arms at side (90'), thumbs up.
-Jump upward as high as possible, flexing the legs to bring the feet under the buttocks.
-Bring knees high and forward for max. lift.
-Repeat quickly upon landing using the same cycling action with the legs.
-Execute rapidly attempting to gain max. height and distance, but not at the expense of repetition rate.

Double Leg Bounds (3x8)
-Start in a half-squat position with shoulders out over the knees, back straight, head up.
-Jump upward and outward using hip extension and thrust of the arms.
-Seek to attain max. height and distance by fully straightening the body.
-Upon landing resume starting position and initiate the next bound.
-"Reach for the sky."

Side Hop (4x8)
-Place two cones (18-26") 2-3 ft. apart.
-Start outside one of the cones with feet together and arms cocked ready to provide lift.
-Jump sideways over the two cones and without hesitation change direction and jump back over the cones; continue this back-and-forth sequence.
-Use arms for upward thrust; thumbs up, elbows 90'.

PLYOMETRIC TRAINING SESSION #7 and #8

Skipping (4x30m)
-Upright position, one leg slightly ahead of the other.
-Drive off the back leg, initiate a short skipping step, thrust the opposite knee hard and fast up to chest level.
-Upon landing repeat the pattern with the opposite leg.
-Thus the pattern is: *right-right-step-left-left-step-right-right*.
-Max. hang-time, minimal ground time.

Double Leg Speed Hop (4x8)
-Back straight, head up, shoulders slightly forward, arms at side (90'), thumbs up.
-Jump upward as high as possible, flexing the legs to bring the feet under the buttocks.
-Bring knees high and forward for max. lift.
-Repeat quickly upon landing using the same cycling action with the legs.
-Execute rapidly attempting to gain max. height and distance, but not at the expense of repetition rate.

Double Leg Bounds (4x8)
-Start in a half-squat position with shoulders out over the knees, back straight, head up.
-Jump upward and outward using hip extension and thrust of the arms.
-Seek to attain max. height and distance by fully straightening the body.
-Upon landing resume starting position and initiate the next bound.
-"Reach for the sky."

Side Hop (*5x10*)
-Place two cones (18-26") 2-3 ft. apart.
-Start outside one of the cones with feet together and arms cocked ready to provide lift.
-Jump sideways over the two cones and without hesitation change direction and jump back over the cones; continue this back-and-forth sequence.
-Use arms for upward thrust; thumbs up, elbows 90'.

PLYOMETRIC TRAINING SESSION #9 and #10

Skipping (5x30m)
-Upright position, one leg slightly ahead of the other.
-Drive off the back leg, initiate a short skipping step, thrust the opposite knee hard and fast up to chest level.
-Upon landing repeat the pattern with the opposite leg.
-Thus the pattern is: *right-right-step-left-left-step-right-right.*
-Max. hang-time, minimal ground time.

Double Leg Speed Hop (4x8)
-Back straight, head up, shoulders slightly forward, arms at side (90'), thumbs up.
-Jump upward as high as possible, flexing the legs to bring the feet under the buttocks.
-Bring knees high and forward for max. lift.
-Repeat quickly upon landing using the same cycling action with the legs.
-Execute rapidly attempting to gain max. height and distance, but not at the expense of repetition rate.

Double Leg Bounds (4x8)
-Start in a half-squat position with shoulders out over the knees, back straight, head up.
-Jump upward and outward using hip extension and thrust of the arms.
-Seek to attain max. height and distance by fully straightening the body.
-Upon landing resume starting position and initiate the next bound.
-"Reach for the sky."

Squat Jumps (3x10)
-Slightly more difficult than rim jumps because there is no assistance from the arms.
-Place hands behind head, drop quickly into half-squat position and explode upward as high as possible.
-Repeat the sequence upon landing, initiating the jumping phase just prior to reaching the half-squat position.

Side Jump/Sprint (3x8)
-Stand on one side of the bench, feet together pointing straight ahead.
-Two cones placed 15-20m from the starting position to act as a finish line.
-Begin by jumping back and forth over a bench for designated number of repetitions.
-Keep trunk and hips centred over the bench and carry the legs fluidly from side to side.
-Emphasize rate of execution not height.
-Upon landing after the last jump, sprint to the finish line.

PLYOMETRIC TRAINING SESSION #11 and #12

Skipping (5x30m)
-Upright position, one leg slightly ahead of the other.
-Drive off the back leg, initiate a short skipping step, thrust the opposite knee hard and fast up to chest level.
-Upon landing repeat the pattern with the opposite leg.
-Thus the pattern is: *right-right-step-left-left-step-right-right.*
-Max. hang-time, minimal ground time.

Double Leg Speed Hop (4x*10*)
-Back straight, head up, shoulders slightly forward, arms at side (90'), thumbs up.
-Jump [illegible]ard as high as possible, flexing the legs to bring the feet under the buttocks.
-Bring knees high and forward for max. lift.
-Repeat quickly upon landing using the same cycling action with the legs.
-Execute rapidly attempting to gain max. height and distance, but not at the expense of repetition rate.

Double Leg Bounds (4x*10*)
-Start in a half-squat position with shoulders out over the knees, back straight, head up.
-Jump upward and outward using hip extension and thrust of the arms.
-Seek to attain max. height and distance by fully straightening the body.
-Upon landing resume starting position and initiate the next bound.
-"Reach for the sky."

Squat Jumps (3x10)
-Slightly more difficult than rim jumps because there is no assistance from the arms.
-Place hands behind head, drop quickly into half-squat position and explode upward as high as possible.
-Repeat the sequence upon landing, initiating the jumping phase just prior to reaching the half-squat position.

Side Jump/Sprint (4x8)
-Stand on one side of the bench, feet together pointing straight ahead.
-Two cones placed 15-20m from the starting position to act as a finish line.
-Begin by jumping back and forth over a bench for designated number of repetitions.
-Keep trunk and hips centred over the bench and carry the legs fluidly from side to side.
-Emphasize rate of execution not height.
-Upon landing after the last jump, sprint to the finish line.

PLYOMETRIC TRAINING SESSION #13 and #14

Side Jump/Sprint (4x8)
-Stand on one side of the bench, feet together pointing straight ahead.
-Two cones placed 15-20m from the starting position to act as a finish line.
-Begin by jumping back and forth over a bench for designated number of repetitions.
-Keep trunk and hips centred over the bench and carry the legs fluidly from side to side.
-Emphasize rate of execution not height.
-Upon landing after the last jump, sprint to the finish line.

Double Leg Bounds (4x10)
-Start in a half-squat position with shoulders out over the knees, back straight, head up.
-Jump upward and outward using hip extension and thrust of the arms.
-Seek to attain max. height and distance by fully straightening the body.
-Upon landing resume starting position and initiate the next bound.
-"Reach for the sky."

Alternate Leg Bound (3x6)
-Similar to the *Double Leg Bound.*
-Relaxed stance with one foot slightly ahead of the other.
-Push off back leg driving the opposite knee hard and fast to the chest, attempting to gain max. height and distance.
-Quickly extend forward with the driving foot, swinging the arms in a contralateral motion (like when sprinting).
-Repeat the sequence driving with the other leg upon landing.

Single Leg Speed Hop (3x6)
-Similar to the *Double Leg Speed Hop.*
-Same stance as the *Double Leg Speed Hop* but one leg is held stationary throughout the exercise.
-Perform a set with one leg then switch legs.

PLYOMETRIC TRAINING SESSION #15

Side Jump/Sprint (4x*10*)
-Stand on one side of the bench, feet together pointing straight ahead.
-Two cones placed 15-20m from the starting position to act as a finish line.
-Begin by jumping back and forth over a bench for designated number of repetitions.
-Keep trunk and hips centred over the bench and carry the legs fluidly from side to side.
-Emphasize rate of execution not height.
-Upon landing after the last jump, sprint to the finish line.

Double Leg Bounds (4x10)
-Start in a half-squat position with shoulders out over the knees, back straight, head up.
-Jump upward and outward using hip extension and thrust of the arms.
-Seek to attain max. height and distance by fully straightening the body.
-Upon landing resume starting position and initiate the next bound.
-"Reach for the sky."

Alternate Leg Bound (3x*8*)
-Similar to the *Double Leg Bound.*
-Relaxed stance with one foot slightly ahead of the other.
-Push off back leg driving the opposite knee hard and fast to the chest, attempting to gain max. height and distance.
-Quickly extend forward with the driving foot, swinging the arms in a contralateral motion (like when sprinting).
-Repeat the sequence driving with the other leg upon landing.

Single Leg Speed Hop (3x*8*)
-Similar to the *Double Leg Speed Hop.*
-Same stance as the *Double Leg Speed Hop* but one leg is held stationary throughout the exercise.
-Perform a set with one leg then switch legs.

***Plyometric exercises taken from:**

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APPENDIX B

PLYOMETRIC TRAINING QUESTIONNAIRE

Please complete the following questionnaire by selecting the number which most closely represents your response to the question.

STRONGLY DISAGREE	**1**
DISAGREE	**2**
NO OPINION	**3**
AGREE	**4**
STRONGLY AGREE	**5**

1. As a result of the plyometric training I feel faster.
2. As a result of the plyometric training I feel I jump higher.
3. As a result of the plyometric training I feel quicker.
4. As a result of the plyometric training I feel stronger.
5. As a result of the plyometric training I feel I have more muscular endurance.
6. As a result of the plyometric training I feel I can maintain a higher level of intensity for a longer period of time.
7. Plyometric training has enhanced my game performance.
8. Muscle soreness from the plyometric training did not effect my game performance.
9. Muscle soreness from the plyometric training did not effect subsequent practice sessions.
10. Plyometric training has enhanced my rebounding ability.
11. Plyometric training has enhanced my ability to penetrate on offense.
12. Plyometric training has enhanced my defensive capabilities.
13. Plyometric training has enhanced my shot blocking abilities.
14. I enjoyed the plyometric training.
15. Plyometrics was an effective mode of speed and jump training.
16. The plyometric training program was sport specific.
17. Instruction regarding plyometric exercises was clear and concise.
18. Demonstrations of plyometric exercises were effective.
19. I felt I had a sufficient strength base for participation in the plyometric training.
20. The strength maintenance program was successful in maintaining my strength base.
21. Plyometric training was an effective and efficient use of supplemental training time.
22. The plyometric training sessions were too difficult.
23. Muscle soreness was a confounding factor in test performance.
24. Plyometric training seemed to aggravate my chronic injuries.
25. Sometimes my test performance was limited because my muscles were too stiff.
26. Testing was sometimes painful because of chronic injuries.
27. Motivation was an important factor in the testing.