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THE EFFECTS OF SQUATS AND PLYOMETRIC TRAINING  
ON SELECTED MEASURES OF LEG POWER IN MEN

By

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B.A., University of Montana, Missoula, 1971

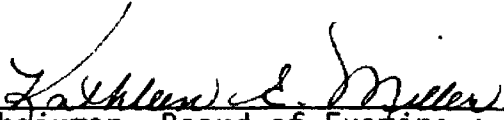
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The Effects of Squats and Plyometric Training on Selected Measures of Leg Power in Men (60 pp.)

Director: Dr. Kathleen Miller *Kem*

This investigation compared the effects of barbell squats and plyometric loading using countermovement jumps on vertical jumping ability and the Margaria-Kalamen and Orthotron anaerobic power tests, to determine an effective method of training explosive leg power for recreational athletes. The final analysis was done with twenty-four male college students who were randomly assigned to either the squat group (N = 12) or the plyometric group (N = 12). The squat group performed 3 sets of 6 squats and 3 sets of 10-15 calf raises. The plyometric group performed 3 sets of 10 vertical jumps and 3 sets of 10 long jumps, emphasizing a powerful countermovement with each repetition. Both groups trained three times per week for seven weeks with progressively increasing resistance. Pretest and posttest measurements were analyzed for within-group gains, treatment effects, interactions, and within-group isokinetic power gains related to training velocity.

The results showed: the squat group improved significantly in all power measures; the plyometric group gained significantly only in vertical jump power; no statistically significant treatment effects or interactions were found; and no significant within-group differences were found between the slow and fast isokinetic speeds for the squat group, or for the plyometric group.

For the recreational athlete, the results of this study do not suggest either method of training is superior.

## ACKNOWLEDGEMENTS

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## Chapter 1

### INTRODUCTION

Explosive leg power specific to vertical jumping ability is required by many sports including high jumping, volleyball, and basketball. However, no consensus exists as to the best way to train vertical jumping ability, or leg power.

By definition, power is a function of force and velocity. When graphed, force is plotted along the abscissa and velocity along the ordinate. Human power performance describes a negatively accelerated curve sloping down from the ordinate to the abscissa with the rough appearance of a ski jump. The goal of power exercises is to shift this force-velocity curve to the right, or to increase the force generated at any given movement velocity along the curve.

On one hand, slow strength exercises, the parallel squat, for example, have been called improper for improving power. Wilt (66), Yessis (67), and Bartels (5) stated many athletes of great strength are unable to produce explosive leg power. Similarly, Considine (21) used the vertical jump and other measures to show increased strength occurred with increased power, but found gains in strength did not correlate well with gains in power. Costill et al. (23) found a high correlation between squat strength and stair climbing power, but a low correlation between squat strength and vertical jumping ability.

On the other hand, Stone and Garhammer (54) felt strength movements,

in emphasizing force, were an effective way to increase power, particularly in the low velocity range. They also stated exercises emphasizing strength and speed will optimize power performance. McLaughlin (5) said strength gained from squats will increase the take-off velocity of the vertical jump. Stone et al. (55), Silvester et al. (53), and Wathen (65) have shown that slow speed strength movements, using barbell squats, will produce a significant increase in vertical jumping ability.

The advantages of barbell squats when compared to machines for increasing explosive leg power are sport specificity (30,55,65) and economy. Free weights are relatively inexpensive and they have been shown to increase vertical jump (VJ) power (5,53,55,66). Other types of weightlifting exercises such as olympic lifts may be more effective than the squat and may, in common with plyometric exercises, utilize elastic recoil and the reflex arc (30,31). A muscle stores energy in the fashion of a gum band when it is stretched during eccentric contraction. Certain jumping motions exemplified by olympic lifts and the vertical jump preceded by a leap activate elastic recoil and the stretch reflex. Olympic lifts, which include the power clean, require greater skill and more coaching to perform well than the squat, and may not be convenient for the recreational athlete. For training the nervous system, however, olympic lifts may be more appropriate than squats.

Plyometric exercises may be more sport specific for improving vertical jumping performance than squats. Plyometrics include VJ drills, and apply the principle of specificity to jumping activities. Blattner and Noble (7) and Clutch et al. (20) have shown that plyometric depth

jumping drills increase vertical jumping ability. Virtually every other exercise mode using freeweights and machines has also been used to increase vertical jumping ability, but experiments comparing methods have had inconsistent results.

The role of plyometrics in power training is not yet defined. Research findings about muscle elasticity and reflex potentiation, the two mechanisms fundamental to plyometric loading, have not been applied to developing an optimum plyometric training program. Plyometrics have been used in conjunction with weightlifting exercises (20,49,57,58,62) and alone (7,32) to develop leg power. For the recreational athlete, plyometric loading may be important in increasing functional leg power and VJ performance. For skilled power athletes, plyometrics may improve performance by presenting a different training method, and by emphasizing a different area of the force-velocity curve.

The jumping from height, or depth jumping, exercises often used in plyometrics may aggravate or create lower body joint problems (7,50), and training which utilizes rapid eccentric contraction may also cause muscle injuries (4,50). This thesis did not use depth jumping; the bounding and leaping drills used in this study have not been evaluated as a training method, so far as is known, but may present less risk of injury than depth jumping.

Three types of vertical jumps were used to measure performance: the static squat jump (SJ), the countermovement jump (CMJ), and the depth or drop jump (DJ). Bosco et al. (14) noted a 43% increase in power if the VJ is preceded by a rapid squatting countermovement (CMJ), over the power of a vertical jump performed from a motionless squat (SJ) position.

Bosco and colleagues also showed the DJ, as used by Blattner and Noble (7), generated considerable more power than even the countermovement jumps. However, myoelectric recordings of the three types of jumps indicated greatest motor unit activity per force unit in the CMJ. In terms of power training then, the CMJ may have greater impact on neuromuscular function than depth jumping. If the potential for injury from plyometric loading can be reduced and still yield an effective training mode for explosive leg power, plyometrics will share with squats the advantages of economy and sport specificity.

#### The Statement of the Problem

This investigation proposed to compare the effects of barbell squats and plyometric loading with countermovement jumps on vertical jumping ability and the Margaria-Kalamen and Orthotron anaerobic power tests, to determine an effective method of training explosive leg power for male recreational athletes aged 18 to 30 years.

#### Null Hypotheses

1. No significant differences in power will occur within either group following training.
2. No significant differences in power will occur between the groups following training.
3. No significant differences in isokinetic power will occur within either group, between the slow and the fast speed, following training.



### Alternative Hypotheses

The alternative hypotheses were: strength training will increase power, significantly, for both the squat and plyometric groups; treatment effects will be found between the groups; furthermore, the squat group will make significantly better within-group power gains at the slow isokinetic speed than the fast speed, and the plyometric group will make significantly better within-group gains at the fast isokinetic speed than the slow.

### Assumptions

1. Subjects recorded all activities.
2. Subjects did not participate in competitive activities regularly (as a team member, for example), nor additional leg strength training.
3. Subjects did not partake in aerobic leg work in excess of about 1,000 calories or 90 minutes per week, and did not train for endurance on the same day as strength if possible.
4. Subjects gave maximum effort during training and testing sessions.

### Definitions

**Recreational Athlete:** A habitually active sportsman who engages in any type of physical exercise requiring muscular strength or endurance several times a week.

### The Importance of the Study

The neuromuscular mechanisms, elastic recoil and reflex potentiation, of plyometrics have been the subjects of much research. Little has been done, however, in applying theory to training practice. The depth jump type of plyometrics has been shown to produce significant performance improvement in the vertical jump, but other jumping styles have not been used experimentally to determine their effectiveness for power training. The addition of more information on training procedures should be of interest to recreational athletes, and provide insight for power athletes and coaches as well. Because squats are a standard strength exercise, and the vertical jump is a standard measure of explosive leg power, they served as the base of comparison in this study. The Orthotron and Margaria-Kalamen anaerobic power tests were expected to yield additional useful information.

## Chapter 2

### REVIEW OF LITERATURE

The first references to plyometric training appeared in Russian sports literature in the mid-1960's (61,62), and the concept of elastic muscle energy was being investigated experimentally in Europe. A definition of plyometric training was offered by Wilt (66) in 1975, the first known reference in American sports literature, and his spelling is used in this report. Wilt defined plyometrics as a type of loaded isometric contraction involving the stretch reflex. Blattner and Noble (7) refined this further as a concept applying the principle of training specificity to the generation of explosive muscle contraction. In short, plyometric loading is a training concept involving muscle elastic recoil and the stretch reflex.

Barbell squats are a well-known exercise, and form the base of exercise routines used by competitive strength and power athletes. Squats are an established exercise for strength and power training.

#### Sources of Elastic Energy in Muscles

From work with isolated animal preparations, two sources of elasticity have been identified within the muscle, the parallel elastic component, and the series elastic component. The elastic elements in parallel with the contractile myofibrils are the sarcolemma and fascia. The series elastic elements are the myofibrils and muscle tendons.

Investigations of these two sources of elasticity in isolated preparations have variously found one or the other more important, depending on the method of the study; this is the case with investigations of the source of elasticity in humans. However, the consensus is that the parallel elastic component is a passive elastic source operating at the extreme ranges of stretch (17,45,59), and is not significant in plyometric type activities which have a short range of motion.

Stretch experiments examining the series elastic components, the crossbridges and tendons, have determined that the myofibrils contribute more to elasticity than the tendons (43). In plyometric loading, muscle elasticity is mainly a function of the actinomyosin crossbridges (8,9, 45).

Elastic recoil is most effective at high eccentric stretch rates immediately followed by concentric contraction. Bosco et al. (12) and Cavagna (17) have suggested a possible mechanism. During rapid stretching, the myosin heads are forcibly rotated backwards, absorbing mechanical energy. But with slow rates of stretch, and slow coupling times, the myosin heads tend to slip, reforming lower stress crossbridges. The realignment of the myosin heads results in dissipation to heat of stored mechanical energy, and a decrement of elastic recoil. Optimal use of elastic energy requires rapidly coupled eccentric and concentric contractions.

#### Elastic Energy in Plyometric Exercises

The increase in work performance that occurs in the elastic recoil of an active muscle has been extensively investigated in human

experiments. Among the findings are: short ranges of motion during the eccentric phase generate greater elastic recoil in the concentric phase than long stretches. With this, optimum storage and utilization of elastic energy depends on: fast stretching; high force continuing to the end of eccentric stretch; and a short transition phase, or coupling time, between eccentric and concentric contraction (8).

Other interpretations, by Bosco and Komi (12), Cavagna (17), Asmussen and Bonde-Petersen (2), and Cavanagh and Komi (18), are that rapid eccentric contraction serves to cock the myosin heads (12,17), and to take up slack in the series elastic component (2,17,18). In application to activity, these factors reduce the time it takes a muscle to develop tension, which results in more rapid contraction and leads to an increase in VJ take-off velocity.

### The Stretch Reflex in Plyometric Exercises

The nervous control by which muscles are activated in plyometric exercises has not been completely resolved. Work with men in the three types of VJ tests led Bosco et al. (14) to conclude elastic recoil is more important than reflex potentiation. Their findings indicate the stretch reflex plays a minor role in VJ performance.

Recent investigations by Eklund and colleagues (27,28), and Burke et al. (15) have not clarified whether the cortical or segmental reflex arc is predominant during elastic stretch. Burke et al. showed the cortical loop predominant in an experiment concerning anticipated stretch in humans; also from human experiments, Eklund et al. showed the segmental loop predominant in unresisted stretch, and probably predominant in

resisted stretch.

Relative to training, an explanation offered by Hayes (34) is that the supraspinal loop controls motor unit coordination and recruitment. Whether the spindle afferent loop responds to strength training is not known. If the occurrence of reflex potentiation from jumping operates through the cortical loop, plyometric training may train it.

### Muscle Fiber Type and Performance

That fast twitch (FT) fibers are the primary contributor to plyometric performance, rather than slow twitch (ST) fibers, is well documented by the elastic energy research of Bosco and Komi (9,11), Komi et al. (41), Komi and Viitasalo (42), and Thorstensson et al. (57,58). An interesting recent discovery by Viitasalo and Bosco (63) indicated individuals with a high slow twitch fiber ratio may be able to outperform individuals with a high FT fiber ratio in the DJ test. Three ST and three FT fiber predominant men participated in SJ, CMJ, and DJ tests during which myoelectric activity was recorded. The SJ was performed better by the fast twitch predominant men, who had a fast rise time in concentric force production, and the DJ was performed better by the slow twitch men. No significant difference was found between the two groups in the CMJ. Viitasalo and Bosco believed these results showed possible differences in crossbridge life between FT and ST muscle fibers which favored the sustained eccentric contraction times in the DJ test.

The meaning of these results for plyometric training is unclear. Nonetheless, research into fiber type by Thorstensson and colleagues (58) and Schmidtbleicher and Haralambie (51) has shown a decrease in

contraction time following strength training, and Viitasalo and Komi (64) have found the genetic determination of fiber type ratio a less important factor in contraction speed than training.

#### Training Velocity and Intensity in Vertical Jump Performance

Squats and plyometric loading have both been shown to increase vertical jumping ability, and this raises a question about the importance of training speed for building explosive leg power. Squats develop slow strength (54); as strength gains are velocity limited, the primary influence of squats on the force-velocity curve is a right-shift at low velocities (5,35,54). This strength is developed by training with high intensity contractions (4,30,54), and development of high levels of tension is a function of motor unit recruitment and synchronization (3, 34). Relative to plyometrics, Bosco and others (14) showed high levels of motor unit activity during VJ tests; plyometrics, then, develop high intensity contractions. From research in velocity-specific contractions, Coyle (5) said maximal effort at high velocities will develop little tension.

The implication seems that plyometric loading and squats cause similar neuromuscular adaptations. Hayes (34) reasoned that muscle tension is created by a stretch load to which motor unit synchronization is a trained cortical reflex response; with strength training, tension development becomes more rapid (3) and motor unit synchronization occurs at lighter loads (34). If the supraspinal reflex arc is involved in strength training, a parallel development of reflex pathways may be the tension response to loads in squats and plyometrics. Therefore, neural

adaptation may be more related to strength than velocity in plyometrics. Also, power performance is generally related to FT fiber predominance (26,51,58), and FT fibers are recruited at high intensity contractions (58); success in both exercises has been shown to be related to fiber type.

The importance of training for power at a velocity specific to the sport is well established (5,16,24,25,43). The connection between optimum training velocity, or mode, and vertical jumping ability has not been defined. Two studies, by van Oteghen (60), and by Genuario and Dolgener (33) specifically investigated the effect of training velocity on vertical jumping ability in women athletes. Using isokinetic exercise, neither study was able to establish a relationship between VJ performance and training velocity. Another study using female college students, by Copeland (22), separated the participants into groups by vertical jumping ability. These women training on an isokinetic leg press machine at 250 degrees per second, which was determined as the average movement speed of the femur in the vertical jump. The results indicated isokinetic power training improved scores for the low ability group, but not the high ability group. The effect of training in Copeland's study depended on the initial VJ ability of the subjects. From his work comparing the effects of isotonic exercise to isokinetic training on VJ ability, Wathen (65) reasoned that tension and motor unit activation are as important in developing explosive power as training velocity.



### The Findings of Plyometric Training Studies

Several studies have evaluated the effects of plyometric exercises on performance. The results indicated significant improvements are possible with this type of exercise. Except for two experiments reported by Clutch et al. (20) which used two day a week training, all studies used three day a week training schedules. Other parameters varied.

A sixteen week study comparing heavy weight training of the leg extensors to light weight, explosive jump training was undertaken by Komi et al. (41). Two groups totalling 18 students were evaluated for a number of factors, including vertical jump performance. Of interest is the finding that, after eight weeks, the explosive jump group decreased VJ performance by 9%. After 16 weeks, the jump group showed an overall improvement in the VJ, but the "valley" in VJ performance at mid-study was unexplained.

Polhemus and Burkhardt (49) examined weight training alone and weight training combined with plyometrics in a six week study involving college football players. Three groups were used, weights only, weights plus depth jumping, and weights plus weighted depth jumping. All three groups showed significant improvements in squats and power cleans. The VJ was not tested, but the findings indicated greatest gains occurred in the weights plus weighted depth jump group.

Blattner and Noble (7) conducted an eight week investigation using 48 men which compared isokinetic to plyometric training. The two groups trained three days a week, with the plyometric group training with 3 sets

of 10 repetitions on the depth jump. Resistance was gradually increased for the plyometric group until they were performing the jumps with 20 pounds added to their body weight at the end of the study. Both groups demonstrated significant gains in the vertical jump, but neither was significantly better than the other.

Two experiments reported by Clutch and colleagues (20) compared depth jumps to weight training for increasing leg strength and vertical jumping ability. The first experiment evaluated the performance of 12 male students from a beginning weight training class in a three group change-over design. Following a three week weight training period, the three groups trained with either maximum vertical jumps, .3 meter depth jumps, or with .75 and 1.1 meter depth jumps, twice a week for four weeks; the subjects performed squats after jumping. All groups experienced significant gains, but no significant differences were found between groups in leg extension or VJ performance.

The second experiment by Clutch et al. used 16 competitive university volleyball players and 16 students enrolled in a weight training class. Half of each group was assigned to either of two treatments: weight training combined with depth jumping; and weight training only. Each group trained twice a week for 16 weeks. Each treatment showed significant increases in VJ, but Clutch et al. concluded from the results that the volleyball players did not need the DJ drills due to their daily volleyball training. The non-volleyball players were found to do better in the VJ if their weight training was combined with depth jumping drills. These experiments indicated to the authors that weight training combined with any jumping exercises is as effective as weight training

combined with depth jumping.

Four plyometric training studies used DJ exercises and the fifth used undescribed weighted jumps. The results of these studies revealed that plyometrics can be an effective exercise.

### Population Delimitations

#### Interference of Endurance Work with Leg Strength

A study comparing the effect of training for strength, for endurance, and for strength and endurance simultaneously, disclosed leg strength gains are limited by aerobic work. This ten week training study conducted by Hickson (36) used three exercise groups: a strength group which exercised five days per week in 30-40 minute workouts; an endurance group which exercised 40 minutes per day six days a week; and a group which combined the workouts of both the strength and endurance groups. Hickson found that after seven weeks of training, the strength of the combined strength and endurance group leveled off and dropped during the last two weeks, while the strength group continued to gain leg strength through the ten week period. Hickson suggested this result came from the inability of the leg muscles to continuously adapt to both forms of exercise. In this thesis, subjects were requested not to participate in more than about 90 minutes per week of endurance exercise, not to train aerobically on the same day as the strength workout, and not to partake in competitive sports, nor any additional leg strengthening exercises.

### Sex Related Differences in Vertical Jump Performance

The results of investigations by Komi and Bosco (40) and Bosco and Komi (10), using 57 and 226 subjects, respectively, brought to light differences between sexes in leg power and ability to store elastic energy. From data obtained by SJ, CMJ, and DJ measurements, the scientists found women better able than men to utilize stored elastic energy in the CMJ and the DJ, but men were able to tolerate higher stretch loads in the DJ, and to outperform women in the three VJ tests. For this thesis, only men were used as subjects.

### Age Related Differences in Vertical Jump Performance

The work of Margaria et al. (46) revealed leg power to increase with age to 20-30 years and then to gradually decline. Likewise, with 226 subjects (113 males) the influence of aging on vertical jumping ability was examined by Bosco and Komi (10). Bosco and Komi suggest that optimum performance in the vertical jump is reached in both sexes between the ages of 20 and 30 years. Additionally, the investigators found the effects of aging on muscle elasticity and the stretch reflex to parallel the effects of aging on concentric contraction. This thesis used subjects aged 18 to 30 years.

### The Exercise Regimen

#### Squats, Sets and Repetitions

Investigations of the best number of sets and repetitions (reps) for producing the greatest strength gains cover a variety of combinations. In developing a strength training protocol for this study, the

consideration in reviewing literature was to identify a trend. If ten citations (1,3,4,6,19,52,53,56,57,58) indicate common acceptance, then 3 sets by 6 reps, three times a week is the optimum routine for strength training.

### Plyometrics, Sets and Repetitions

Plyometric training has not been as well explored as other strength training methods in terms of sets and reps, except perhaps in Russia (61, 62). Possibly, the optimum barbell routine of 3 sets by 6 reps will serve for this exercise also. Blattner and Noble (7) used a 3 by 10 (sets by reps) combination for a weekly total of 90 reps in their eight week study comparing isokinetic exercise with plyometric and found a significant increase in vertical jumping ability. Blattner and Noble used DJ exercises three times a week.

Several studies used plyometrics combined with weight training. In a program of weight training workouts followed by plyometrics, Polhemus and Burkhardt (49) used a 3 by 10 combination of DJ exercises, in three day a week workouts for six weeks, totalling 90 reps per week. Two studies by Thorstensson and others (57,58) included weight training and plyometrics in the same workout. Thorstensson et al. conducted eight week studies with three day a week workouts, with 3 by 6 squats followed by 3 by 6 vertical jumps and long jumps. In the first of two experiments by Clutch and colleagues (20), 4 by 10 DJ drills were combined with 3 by 6 squats. In the second experiment, 4 by 10 depth jumps were combined with 3 by 6 squats, dead lifts, and the bench press. Both of these experiments used twice a week training.

An article describing a plyometric loading program for ski jumpers by Gaskill (32) illustrated plyometric exercises, and discussed programs in terms of total jumps performed. The suggestion is for beginners to perform 20 to 30 jumps per workout, and Gaskill recommends over 300 jumps in a 45 minute workout for a person who has trained over three years with plyometrics. Gaskill said a beginner should do two to three different exercises, and 2 sets of 5 to 8 reps for each exercise; the experienced should do 3 sets of 10 to 12 reps of different exercises for 300 or so total jumps. Basically, Gaskill recommends 3 sets of 8 to 12 reps for each plyometric exercise, three times a week. Neither Gaskill nor the studies by Thorstensson used depth jumping exercises.

Describing a number of different exercises for the training of Russian jumpers, Verhoshanski (61,62) also recommended a range of combinations. Depending on the nature of the training, Russian athletes used routines of from 2 to 40 sets and from 5 to 7 through 8 to 10 reps of plyometric exercises, performed once or twice a week. Verhoshanski suggested 8 to 10 reps for dumbbell broad jumps, and 6 to 8 reps for vertical jumps. For beginning athletes, Verhoshanski said either plyometrics or weight training is suitable, and for intermediate athletes, Verhoshanski preferred weight training over plyometrics for improving jump performance. For the training of highly skilled athletes, combined weight training and plyometrics are used. Concerning depth jumps, Verhoshanski recommended 20 to 40 reps per workout combined with barbell exercises for the trained sportsman.

The apparent consensus for plyometric training, then, is a 3 by 10 combination, three days a week. However, this routine does not seem

to be based on investigative evidence.

### A Brief Analysis of the Vertical Jump

Performance in the VJ is a function of take-off velocity, and requires explosive power from the hip and knee extensors, and the ankle plantar flexors. An analysis of the contribution of different body segments to VJ take-off velocity was made by Luhtanen and Komi (44). Their results indicate the quadriceps contribute 56%, calves 22%, hip extensors 10%, arm swing 10%, and head swing 2% to total performance. The data were recorded from a non-elastic jump, without a preceding countermovement.

Individual joint contributions to VJ performance were determined by Hubley and Wells (37) by measuring work output. Arm swing was controlled in this study by having subjects hold their hands on their hips while being tested in maximal countermovement and static squat vertical jumps. Although considerable variation was found between individuals in the relative amount of work performed by the hip and knee extensors, little difference was apparently found between the jump styles. These investigators found that the knee extensors contributed roughly 49%, hip extensors 28%, and ankle plantar flexors 23% to total VJ work.

Because plyometrics are specific to vertical jump performance, no other exercises were necessary in this program; all the muscle groups used in training were used in the VJ test. For the other program, squats trained the knee and hip extensors, but an additional exercise, standing calf raises, was necessary for complete training of the muscles used in vertical jumping. The contributions to take-off velocity of arm and

head swing are possibly related to technique; as such, no effort was made to include these body parts in the strength training schedule.

Changes in vertical jumping ability from practice may not be significant. Heusner (35) suggested jumping is a common athletic skill for which motor learning is probably a minimal influence. Improved VJ performance after training would therefore probably be a function of power development.

### Summary

Several training studies using plyometrics have produced increases in explosive leg power, however, little is known about optimum ways to train with this type of exercise. Whether plyometric exercises are appropriate when used as the sole method of training is not known. Blattner and Noble (7) found an increase in VJ performance with depth jumping training of previously untrained students. Verhoshanski (61,62) recommends weight training or jump exercises for beginning jump athletes, and weight training alone for intermediate jump athletes. Combined high intensity weight training and plyometric routines are reserved for advanced athletes in Russia. The indication from Russian experiments is that at intermediate levels, jump exercises are less important than weights for improving jump performance. According to Verhoshanski, plyometrics become increasingly important at higher levels of jump mastery. Investigations of changes in vertical jumping ability resulting from depth jumps combined with weight training by Clutch et al. (20) found that depth jumps were effective in producing gains, but not more effective than the daily practice in jumping sports. More research is needed



into the requirements of different levels of jumping and power skills to learn how to best utilize weight training and plyometrics. The present investigation should supplement the research concerning plyometrics.

## Chapter 3

### METHODS AND PROCEDURES

#### Research Design

A pretest-posttest two-group design was used to evaluate the training effects of squats and plyometrics on three power measures over a seven week period. This experiment examined the differences within and between the two training groups.

#### Statistical Treatments

A t-test for correlated groups was used to examine the within-group gains from pretest to posttest. Between-group comparisons were evaluated with ANCOVA using linear regression techniques. The Pearson r was used for all correlational analyses. For all analyses, the alpha level was set at .05.

#### Subjects

Thirty-three recreational athletes interested in increasing leg power were recruited at the University of Montana during Winter Quarter 1983 for participation in the study. The 33 subjects were randomly assigned to either the squat group (N = 16) or the plyometric group (N = 17). All were offered a Physical Education credit (HPE 100) for participating. Of the original 33, five subjects wished to participate but did not fit within the population guidelines of the study.

Twenty-eight of the subjects met the following criteria:

1. Male aged 18 to 30, with no history of lower back, hip, knee, or ankle problems, and no injuries within the past year.
2. Not presently engaged in competitive activity on a regular basis.
3. Not presently participating in aerobic training in excess of about 1,000 calories or 90 minutes per week.
4. Not presently performing any lower body strength or power work not part of this study.

Five subjects did not meet these criteria, and were not included in the analysis. Of these five, two were overage at 32 and 34 years, two others were University of Montana basketball players who were not involved in team games during the study period, but were otherwise fully participating in team training, and a fifth was not able to complete all of the tests.

Of the 28 subjects on whom data were collected, one decided to discontinue participation before training began, one was lost due to work and class loads at midterm, another completed the training period but moved out of the area the weekend before posttesting, and a fourth was not used due to incomplete data (off-scale on a posttest Orthotron measure). Ultimately, 24 subjects, 12 in each group were used in the statistical analysis.

### Power Measurement

#### Pretesting and Posttesting

The subjects were tested in the Human Performance Laboratory at the

University of Montana. For the pretest measurements, a familiarization session was scheduled for either Tuesday or Wednesday, January 11 or 12, 1983, to acquaint each subject with the test and training procedures, to obtain their informed consent, and to obtain their medical and training histories (sample forms are included in Appendices A, B, and C).

Orthotron testing required more time than the other tests, and subjects were tested on this measure Thursday. Vertical jump and stair run testing was done on Friday the fourteenth. Subjects were instructed to perform neither aerobic nor non-aerobic leg exercise on the test days, until after testing.

Following the seven week training period, posttesting was conducted in the same sequence as pretesting. On Monday, March 7, only Orthotron testing was done. On Tuesday, the vertical jump and stair run were conducted. Due to scheduling problems, several subjects were tested on some or all measures Wednesday, March 9.

Two individuals, the investigator and assistant, were qualified by training and experience, and conducted all tests. For all testing, each individual performed the same function at posttest as at pretest.

### Orthotron Protocol

For each leg, the right leg first, this procedure was used:

1. When the subject was seated in the Orthotron Isokinetic Knee extension machine (Cybex, Division of Lumex), adjustments were made to each individual as described in the Orthotron manual. Straps were fastened across the working thigh and behind the working ankle (the working leg exerted against a padded lever arm). The subject was instructed to

hold the handles built into the seat and to keep his dorsal surface in contact with the seat.

2. The subject was given a 10 rep warm-up at 120 degrees per second, corresponding to machine setting 5, followed by a rest period. For testing, 3 reps were performed in succession at each load, with a dead stop between reps. In performing the extension, the subject was instructed to surge rather than explode against the resistance of the machine. Each test was followed by a one minute rest.

3. The sequence of loads was 60, 180, and 240 degrees per second, corresponding to Orthotron settings of 3,7, and 9.

4. The score at each load was the best of the three successive efforts.

#### Vertical Jump Protocol

A trend is developing for the use of the VJ plus the Lewis formula (29) as a measure of explosive leg power (56). The results of this test can be correlated with those of other investigations into strength and power training. Vertical jumping ability was measured by the jump and reach test. For each subject, age, and the height and weight in clothing worn for the testing were recorded at the time of testing. Weight was measured on a Health-O-Meter balance scale. For the vertical jump test, this procedure was used:

1. Three commercially available memo boards of plastic coated card stock, 35 by 27 centimeters, were stacked length-wise and taped immediately above a door jam. The bottom of the stack was at 86 inches above the floor.

2. The subject was instructed to hold a felt-tip pen with the shaft across the palm, between the tip of the thumb and first knuckle of the index finger of the preferred hand. A reference line on the pen was aligned with the tip of the thumb.

3. For recording reach height, the subject was instructed to reach as high as comfortably possible on tip-toes, and scribe a mark on the card stack in the form he would use when jumping.

4. Jumping pointers were described and demonstrated to the subject as at the practice session. The pointers were: to use a double arm swing and rapid countermovement jump style, with no steps, movement initiated from a dead stop; optimum depth of squat was 115 degrees of knee flexion; optimum foot spacing was 5 to 10 inches laterally, and about 5 inches anterior-posteriorly (38).

5. The subject was allowed an individually selected warm-up of non-jumping activities which may have included stretching and light resistance exercises.

6. The subject was allowed three sub-maximal practice jumps followed by three maximum efforts, each separated by at least 30 seconds.

7. Measurements for reach height and vertical jump height were approximated to the nearest half-inch; the score used was the best of three trials.

#### Stair Run Protocol

Following the VJ test by several minutes, the subject was tested on the Margaria-Kalamen stair run (29) with the following procedure:

1. Times were measured with a Dekan Automatic Performance Analyzer,

Model 741 (Dekan Timing Devices). With the timing mats out of place, to prevent overuse damage, the subjects were given three sub-maximal trials separated by at least 30 seconds.

2. With the timing mats in place, three maximum efforts were recorded, each separated by at least 30 seconds. The approach run was initiated from a dead stop. The score was the best of three trials.

3. The Margaria-Kalamen power test requires the subject to take three stairs at a time; this modification results in greater power output than in the original Margaria test, which requires taking only two stairs at a time (29). As described by Fox and Mathews (29), the approach run to the staircase should be a 6 meter distance. The approach run to the staircase for this study was 4.72 meters; therefore the results of this study may not correlate with other studies. Time was recorded between the third and ninth stairs. The vertical elevation between the third and ninth stairs was 1.05 meters.

#### Power Calculations

Power in the vertical jump was calculated from the Lewis formula (29). The metric units formula for power is the square root of 4.9 times bodyweight in kilograms times the square root of the jump height in meters. Power is expressed in kg-m/sec. The formula for calculation of stair run power is bodyweight in kilograms times the vertical height in meters between the first and last test stairs; this quantity is divided by the time from the first to last test stair (29).

### Training Procedure

Both groups trained three times per week, on Monday, Wednesday, and Friday for a seven week period. Two non-consecutive holidays reduced the number of sessions from 21 to 19. Each participant was required to log attendance, sets and reps performed, and weights jumped with or lifted. The subjects were also asked to log all athletic type activities engaged in during the training program; requested not to perform any additional anaerobic leg work; nor more than 90 minutes of aerobic work per week, particularly not on a strength training day; nor should they have been involved in any competitive sports programs. Participants missing more than three workouts which were not made up within a week of the absence were dropped from the study. Proper technique was demonstrated at the beginning of the training program, and workouts were supervised throughout the period. Depending on the group, these exercises were performed:

#### Squat Group

Squats were performed with an olympic barbell on the shoulders behind the neck in the manner described by Johnson and Nelson (38) and McLaughlin et al. (43,44). Rules of competition require the parallel squat be performed to a depth at which the upper thigh breaks parallel with the floor (43,44). However, several studies using the squat as a training mode or test have subjectively defined adequate depth as when the bottom of the thigh breaks parallel. The latter seems the form preferred by recreational athletes and non-competitive weightlifters (unpublished observations).



Because the calves contribute 22% to overall vertical jump performance, squats alone may be insufficient for optimum training for explosive leg power. Calf work was performed on a plate-loading calf machine which placed the load on the shoulders. The participant was instructed to stand on the balls of his feet on a wooden block, thus obtaining a full range of motion of the ankle. Participants were advised not to flex the knees during a set.

The squat group trained using the following protocol:

1. Squats: 3 sets by 6 reps preceded by two warm-up sets of 6 to 10 reps. When the subject was able to do 6 reps on his last set, he was urged to increase the load five or ten pounds for his next workout.
2. Standing calf raises: 3 by 10 to 15 preceded by two submaximal warm-up sets.
3. No mixing between the exercises was allowed, but the order of performance was optional.

### Plyometric Group

The plyometric group performed countermovement jumps including double leg vertical jumping and long jumping. Subjects were instructed to strive for maximum height or distance with each rep, rather than to perform a complete set by using less intense jumps. After the first week of training subjects were urged to jump with a vest fitted with pockets for weights, or with dumbbells in their hands, to increase resistance. The plyometric group trained with the following protocol:

1. Light warm-up of stretching and easy jumping exercises.
2. Countermovement vertical jumps, maximum effort each rep,

emphasizing each rep rather than completion of a set half-heartedly,  
3 by 10.

4. Subjects were allowed to perform exercises in any order desired  
with all jumps of the same type in a set.

## Chapter 4

### RESULTS

In the tables following, the Orthotron power measures are indicated as 60, 180, and 240, corresponding to machine speeds of 60, 180, and 240 degrees per second; the Orthotron power units (peak torque) are foot-pounds. Vertical jump power, calculated with the Lewis formula, is indicated as VJP; the VJP units are kilogram-meters per second. Margaria-Kalamen stair run power is indicated as SRP; the SRP units are also kilogram-meters per second.

Scatterplots were obtained for each power measure relating pretest and posttest scores for each individual; no outliers were detected. All raw data are presented in Appendices E and F.

Table 1 presents the correlation matrix for groups combined. The Pearson  $r$  was used to analyze the relationships among pretest measures, posttest measures, and the reliability of each measure (i.e., pretest-posttest correlations).

Within-group gains in power from pretest to posttest were analyzed using a one-tailed  $t$ -test. Between group differences on posttests were analyzed using multiple regression. An alpha of .05 was employed for all analyses.

Table 2 presents the pretest and posttest means and standard deviations, pretest and posttest between-group  $t$ -ratios, and  $t$ -ratios for within-group gains on the five dependent measures. From these analyses,

Table 1  
Correlation Coefficients for Combined Groups

Test <sup>a</sup>	60	180	240	VJP	SRP
60	<u>0.82</u>	0.89	0.85	0.85	0.77
180	0.87	<u>0.90</u>	0.97	0.91	0.81
240	0.81	0.93	<u>0.86</u>	0.88	0.79
VJP	0.81	0.77	0.73	<u>0.95</u>	0.84
SRP	0.78	0.71	0.67	0.85	<u>0.94</u>

<sup>a</sup>60, 180, and 240 represent Orthotron Power in degrees per second; VJP represents Vertical Jump Power; SRP represents Stair Run Power.

Note: Correlations among pretests are presented above the diagonal, correlations among posttests are presented below the diagonal, and test-retest reliability coefficients are presented in the diagonal.

Table 2  
 Pretest and Posttest Means and Standard Deviations,  
 Between-Group  $t$  Values, and Correlated  $t$  Values

Test <sup>a</sup>	Pretest			Posttest			Within-Group Gains	
	Squats Mean (SD) <sup>b</sup>	Plyo's Mean (SD)	Between-Group $t$ <sup>c</sup>	Squats Mean (SD)	Plyo's Mean (SD)	Between-group $t$ <sup>c</sup>	Squats $t$ -ratios	Plyo's $t$ -ratios
60	224.5 (48.0)	232.8 (23.1)	0.54	251.2 (58.2)	239.2 (36.5)	0.60	-3.82 <sup>d</sup>	-0.82
180	166.0 (49.0)	168.7 (29.7)	0.16	182.7 (49.3)	178.5 (33.5)	0.24	-5.00 <sup>d</sup>	-1.50
240	137.9 (51.4)	141.1 (32.4)	0.18	153.5 (40.4)	147.5 (35.5)	0.39	-2.62 <sup>d</sup>	-1.02
VJP	121.7 (21.6)	117.4 (19.7)	0.50	127.0 (21.8)	121.8 (20.2)	0.60	-3.48 <sup>d</sup>	-2.02 <sup>d</sup>
SRP	161.9 (27.4)	155.9 (21.4)	0.59	166.6 (26.5)	157.1 (20.6)	0.98	-1.93 <sup>d</sup>	-0.50

<sup>a</sup>60, 180, and 240 represent Orthotron Power in degrees per second; VJP represents Vertical Jump Power; SRP represents Stair Run Power.

<sup>b</sup>Standard Deviation

<sup>c</sup>no  $t$  reported here is statistically significant (df = 10, two-tailed test)

<sup>d</sup> $p < .05$ , df = 11, one-tailed test

no significant differences were found between groups on any of the pretest or posttest measures. The squat group increased significantly in all power measures. The plyometric group made significant gains only in vertical jump power. Figure 1 is a graphical presentation of these data.

Table 3 presents the results of a dependent t-test for within-group differences in isokinetic knee extension power gains related to training speed. No significant differences were found for a one-tailed test between the slow and fast speeds for the squat group, or for the plyometric group.

Stepwise regression was employed to examine between-group differences on the five measures, as outlined in Kerlinger and Pedhazur (39). The pretest was entered on the first step and, on the second step, followed by the treatment term (coded 0 = squats, 1 = plyometrics). The F-ratio associated for the treatment term on this step represents the statistical significance of the treatment effect (and the corresponding increment in  $R^2$ ). On the third step, a term was entered that represents the mathematical product of treatment and pretest (e.g., for a subject in the squat group:  $PRE60 * 0$ ). The F-ratio corresponding to this term indicates the degree to which a statistical interaction exists between treatment and pretest: Is, for example, squat training more effective for subjects initially low on PRE60 than for subjects high on PRE60?

Table 4 presents the results from the regression analysis. No statistically significant treatment effects or interactions were found.

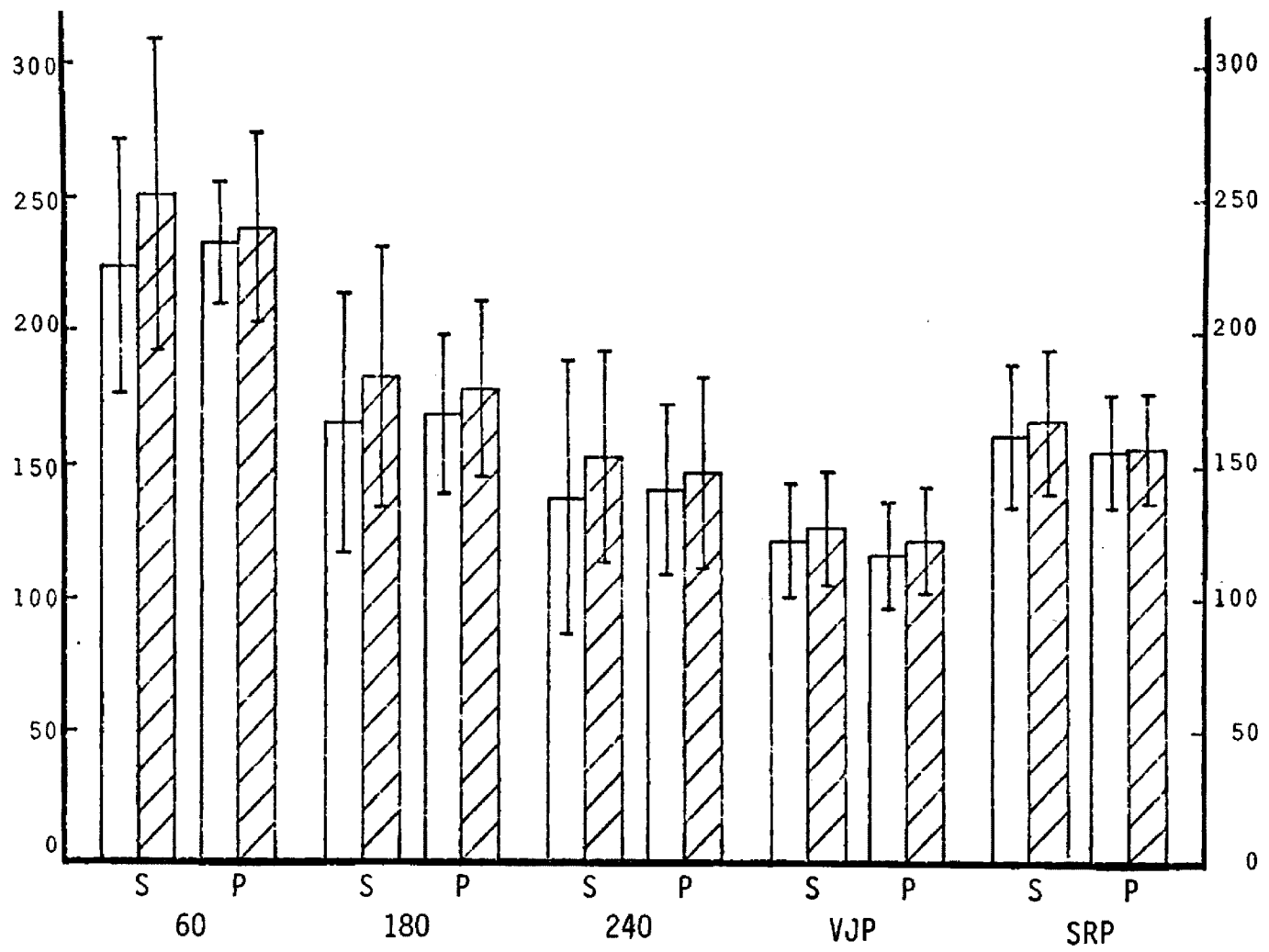


Figure 1

Pre and Post Training Power Means and Standard Deviations  
S = Squat Group, P = Plyometric Group  
( ) = Pretest, (////) = Posttest

Table 3  
 Slow and Fast Speed Isokinetic Dependent  $\underline{t}$  Values

Test	Squats		Plyo's	
	Pre-Post Difference Mean (SD) <sup>a</sup>	60-240 $\underline{t}$ -ratio	Pre-Post Difference Mean (SD)	60-240 $\underline{t}$ -ratio
60	26.7 (24.2)	1.15	6.4 (27.1)	0.01
240	15.7 (20.7)		6.4 (21.8)	

<sup>a</sup>Standard Deviation

Note: No  $\underline{t}$  reported here is statistically significant  
 (df = 11, one-tailed test)



Table 4  
Treatment Effects and Interactions

Test <sup>a</sup>	Treatment Effect (df = 1,21)		Interactions (df = 1,20)	
	$\Delta R^2$	<u>F</u>	$\Delta R^2$	F
60	0.05	3.86	0.00	0.02
180	0.01	0.81	0.00	0.37
240	0.01	1.17	0.00	0.46
VJP	0.00	0.17	0.00	0.04
SRP	0.01	1.52	0.00	0.03

<sup>a</sup>60, 180, and 240 represent Orthotron Power in degrees per second, VJP represents Vertical Jump Power; SRP represents Stair Run Power.

### Summary

The t-test for dependent groups revealed that the squat group made gains in the three isokinetic power measures, in vertical jump power, and in stair run power; and that the plyometric group made gains only in vertical jump power. Another dependent t-test did not find significant within-group differences in gains between slow and fast isokinetic test speeds for either the squat or the plyometric group. ANCOVA, however, showed that neither training method was superior on any of the power tests.

## Chapter 5

### DISCUSSION

This study addressed four questions: First, would both the squat and the plyometric groups make power gains? Second, would differential gains be found between groups? Third, would a statistical interaction be found for any measure? Fourth, would either group make isokinetic power gains specific to the training velocity of that group? This chapter discusses the results of this investigation relative to these four questions and to other studies reported earlier. The meaning of this study relative to training for leg power is also discussed.

The squat and plyometric groups trained at different speeds of knee extension. Three speeds of isokinetic knee extension were selected to see if Orthotron power gains would be velocity specific for each exercise. The squat group was expected to show greater within-group gains at slow test speeds than fast, due to the slow training speed. The plyometric group, however, was expected to show greater within-group gains at fast test speeds. The squat group did not make significantly better gains at the slow isokinetic knee extension speed than at the fast test speed. Similarly, the plyometric group did not make significantly better gains at the fast test speed. These results are similar to those of the studies by van Oteghen (60) and Genuario and Dolgener (33), both of which found no statistical significance between isokinetic training velocity and vertical jump performance. In the present study, gains in slow

and fast isokinetic power were not associated with the speed of exercise training.

The squat group alone made gains in stair run power. The Margaria-Kalamen stair run power test was used because athletes were reported to generate greater power from this three-step test than from Margaria's original two-step test (29). Margaria et al. (46) reported that two steps were the optimum foot spacing for power measurement because the force required to climb three steps is too high and the contraction time is too long. Conversely, step frequency is too short at shorter than two-step spacings. Because achievement of maximum power was not the issue, Margaria's original test may have been the better choice. In life, few activities require the stretch of a leg as in the Margaria-Kalamen test. For this study, the requirement of taking three steps at a time may have masked functional power gains in stair climbing ability for the plyometric group.

Contrary to what was expected theoretically, the plyometric group made significant gains only in vertical jump power. The discussion of this finding is broken down into several component issues: (A) Countermovement jumps as used in this study may have limited effect as an exercise, and depth jumps may be the more appropriate plyometric drill for training. (B) The training protocol for countermovement jumps may have been improper in terms of sets, reps, and weight loads; and plyometrics may not be effective when used alone, but only when used with heavy resistance exercises. (C) The jumping skill level of the subjects of this study may have been too advanced for plyometrics alone to produce power gains in all the measures, and the training protocol may have been

inappropriate for recreational athletes at this skill level.

Plyometric loading with depth jumps has been shown to increase vertical jumping ability in previously untrained individuals (7,20). For trained jump athletes, however, depth jumps have not been more effective than the jumping exercise in regular sport practice. Clutch et al. (20), for example, reported that depth jump drills did not improve jumping ability in collegiate volleyball players who jump as a part of practice. No previous training studies have evaluated countermovement jumps, except perhaps Komi et al. (41). In the study by Komi and colleagues, explosive jump exercises with weights produced gains only after sixteen weeks of training; these jumps may have been countermovement jumps, or static squat jumps.

Bosco and others (14) recorded differences in myoelectric activity between depth and countermovement jumps. They reported that increasing force in the eccentric phase of the DJ occurred with increasing height of drop, up to a point where further increase in eccentric force only produced decreasing concentric force. Greater eccentric force in the DJ, then, translated to greater force in the concentric phase. Bosco et al. found the opposite occurrence in the CMJ; that eccentric force decreased with increasing stretch speed, but the CMJ still generated high concentric forces. The authors speculated that the differences in force and myoelectric activity of the eccentric phases between the drop jumps and countermovement jumps may be related to different motor unit recruitment patterns. They also speculated that these two recruitment patterns may be controlled from different areas of the brain. From their work, Bosco and colleagues suggest that force generation in the DJ is more

elastic than in the CMJ, and greater motor unit involvement is required per unit of force in the CMJ for both eccentric and concentric contraction phases. These scientists found, too, that elasticity made only a slight contribution to performance in the positive phase of the CMJ. Perhaps the CMJ and DJ are different forms of exercise.

Heavy loading of the CMJ contributes to a long stretching phase, associated with a long coupling time between negative and positive work phases. If the coupling time is too long, the stored elastic energy dissipates to heat. To produce a training effect, subjects in the present investigation used increasing weights through the training period. Possibly, loaded countermovement jumps produce force less from elastic energy and more from chemo-mechanical conversion. For what may have actually been non-elastic rebounding then, the present study may have not correctly estimated the tension stimulus necessary for producing power gains in all measures.

Commenting on Russian theory, Verhoshanski (61) believed plyometrics, particularly depth jumps, are effective only when used at the end of a preparatory phase of strength training, and when used in conjunction with other strengthening methods. For the prepared sportsman, Verhoshanski recommended 20 to 40 reps of depth jumps per workout once or twice a week, and he recommended performing depth jumps in the same workout with weight training. Possibly, a synergistic strengthening action occurs when plyometrics are combined with barbell exercises.

Following Verhoshanski's recommendations, Clutch et al. (20) combined weight training with depth jumps, and found gains in vertical jumping ability occurred except for trained volleyball players. Clutch and

colleagues also found gains from, but no difference between, depth jumps and "maximum vertical jumps" when combined with weight training. These authors apparently only considered depth jumps a plyometric exercise. Polhemus and Burkhardt (49) also combined weight training with depth jumps. Thorstensson and others (57,58) combined squats with vertical and long jumps. Blattner and Noble (7) used DJ drills alone, and Komi et al. (41) used explosive jumps with light weights. All these methods of using plyometrics produced gains in either leg strength or power, depending on the measures used. The present investigation supports these studies in producing vertical jump power gains from plyometric training.

Several studies have considered vertical jump improvement relative to the skill level of the subject population. Working with female college students separated into groups by skill level, Copeland (22) determined that the effect of isokinetic training depended on the initial skill level of the population. The results indicated improvement occurred only for the low skill jump group. In a training experiment involving a trained men's volleyball team, Clutch et al. (20) found that plyometric drills were ineffective in improving jump performance; that normal practice and a weight training program were adequate for these players. Verhoshanski (62) inferred from Russian training procedures that plyometrics are useful in training beginning jump athletes, but not more useful than weight training. Additionally, Verhoshanski said that plyometrics are most useful when used with weight training for highly skilled jump athletes, and that intermediate level athletes benefit most from weight training alone.

The predication of treatment effects for any of the measures from others studies was not possible. No other studies comparing squats and countermovement jumps are known.

In the present study, statistical interactions were analyzed to see if the treatment was more effective for subjects with low ability on pre-test measures than with high ability. A study by Copeland (22) did not check for statistical interaction, but found that gains in vertical jump performance from isokinetic training were related to initial jumping ability. Another study, by Clutch and others (20) found a statistical interaction between the groups and the treatment in a four group study measuring vertical jump performance. The interaction indicated that training with depth jumps improved vertical jump performance only for individuals doing no other jumping.

The implications of this study for training to increase leg power are not manifest. For individuals who have been training for leg power on a continuous and regular schedule, heavy barbell work is probably necessary for further power increases. For active but not strength trained recreational athletes, squats may not be more effective than plyometrics for increasing leg power.



## Chapter 6

### SUMMARY

Two groups, twelve men each, participated in this seven week training study to compare the effects of squats and plyometric loading on explosive leg power. Both groups trained three days a week. The training protocol for the squat group was three sets of six squats and three sets of ten to fifteen standing calf raises. The plyometric group performed three sets of ten vertical jumps and three sets of ten long jumps, emphasizing a powerful countermovement.

Within group gains were evaluated with the correlated t-test. The squat group gained in isokinetic knee extension power, in vertical jump power, and in stair run power; the plyometric group made significant gains only in vertical jump power. Analysis of between-group differences using ANCOVA revealed neither group was superior in any power measure.

For the recreational athlete, the results of this study do not suggest either method of training as superior for increasing leg power.

### Conclusions

Based on the results of this study, these conclusions are formed:

1. The countermovement jumps used in this study may be a different exercise from the drop jumps typically used in this country for plyometric training.
2. Appropriate use of countermovement jumps may require their

combination with squats or other weight training exercises.

3. In performing plyometrics, stimulation of the nervous system to improve its reactive ability requires a maximal effort for each repetition.

### Recommendations

Based on the results of this study, these recommendations for further research are proposed:

1. Further research should be conducted to define a protocol for the optimum numbers of sets and repetitions in plyometric training.

2. The importance of adding weight over time, and the point where loading becomes so great in training that plyometrics lose their meaning and become heavy resistance training should be investigated.

3. Comparisons should be made to determine the nature of the similarities in and differences between depth jumps and countermovement jumps for training purposes.

4. An attempt should be made to quantify the type of leg power training appropriate for each level of athletic skill and for each phase of a training year.

5. For intermediate and advanced athletes, programs combining squats with other forms of power training should be analyzed. For example, comparisons could be made between squats with power cleans and squats with plyometrics; squats could also be combined with leg press, isokinetic, or eccentric exercises.

6. Plyometric exercise types and training protocols should be investigated for improving the intermittent bursts of leg power necessary

for predominantly aerobic activities, such as cross country running, the steeplechase, and Nordic skiing.

7. A study similar to the present one should be extended to investigate the effects of squats and plyometrics on multiple repetitions of a measure (e.g., how squats and plyometrics differ on the vertical jump test between the first and the fiftieth non-stop repetition).

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## APPENDIX A

### Medical and Training History

Local Phone \_\_\_\_\_ Name \_\_\_\_\_

Local Address \_\_\_\_\_

1. Please provide complete and accurate information.
2. Are you currently taking prescription medicine? What is the medicine for?
3. Do you now have, or have you ever had any physical injuries requiring medical treatment? How serious was the injury? Please describe the injury and any treatment or therapy, including current status.
4. Please describe the type of previous physical activities in which you participated. What activities are you currently engaged in, not part of this study?
5. Would you like one 100 level Physical Conditioning credit for participating in this study?

## APPENDIX B

### Informed Consent

The purpose of this study is to determine the effects of two methods of lower body strength training on leg power.

You will perform a maximal vertical jump test at the beginning and at the end of the study for determining change in leg power resulting from the training program. You will also participate in a seven week lower body strength program of either squats or plyometric loading three days each week. The group to which you are assigned will be determined by random selection. Both programs are designed to place a graduated increased workload on the lower body, and thereby increase its strength and power.

You may experience muscle soreness at the beginning of the training program. This is not uncommon with new exercises, or new programs for old exercises. If you have ever had lower back, hip, knee, or ankle problems, or any injury within the past year, you will not be permitted to participate in the study. If any problems develop during the training period, you should specifically inform the instructor and you may be referred to medical care. No problems are anticipated, but the reaction of leg joints to plyometric loading cannot be predicted with complete accuracy. Instruction and supervision during testing and the training period will correct performance and minimize risks.

In the event physical injury results from biomedical or behavioral research the human subject should individually seek appropriate medical treatment and shall be entitled to reimbursement or compensation consistent with the self insurance program for Comprehensive General Liability established by the Department of Administration under authority of MCA Title 2, Chapter 9 or by the satisfaction of the claim or judgement by the means provided by MCA, Section 2-9-315. In the event of a claim for such physical injury further information may be obtained from the University Legal Counsel.

By participating in this study, you can explore your capacity for developing explosive lower body power. You can apply this power to recreational and sports activities as long as you maintain, or rebuild after a layoff, an appropriate exercise program. The investigator will be glad to answer your questions relative to exercise training at any time.

The information obtained from this study will be treated as confidential. This information will be used, however, for a statistical or scientific purpose with your right of privacy retained. You are free to discontinue participation at any time, although a commitment for your participation throughout the study is requested.

I have read the foregoing and I understand it and any questions which may have occurred to me have been answered to my satisfaction.

Name \_\_\_\_\_ Investigator \_\_\_\_\_

Date \_\_\_\_\_

## APPENDIX C

### Instructions to Participants

This 7 week, 19 workout training program will end the week before final week. Due to the brief training period and the low number of workouts, your acquisition of great power gains depends on commitment to the exercise program, and on making-up missed workouts. The instructor, John Lukes, will supervise workouts and will contact you to arrange a make-up schedule in the event of an absence.

For statistical interpretation of the results of this study, these requests are made:

Please

1. Record all athletic activities and workouts in the log. Brief notes and approximate times are sufficient. These can be entered to the right of the workout date, after recording the workout.
2. Do not engage in any additional leg strength training, and do not participate in competitive activities regularly.
3. For maximum strength-power gains, try not to exceed about 90 minutes of endurance leg work (jogging, etc.) per week, and try not to do endurance work on the same day as strength work.
4. Give a maximum effort during the testing and training sessions, and try to increase 5 or 10 pounds a week.

If any problems arise during the training program, please contact me at any time. I will gladly help you design a training schedule for any purpose.

John Lukes: Home: 728-1635 School: 243-4211 (messages)  
2402 Thames Field House, Room 213

APPENDIX D

Recreational Activities

	Alpine Skiing	Basketball	Bicycling	Gymnastics	Handball	Ice Hockey	Jogging	Nordic Skiing	Physical Training	Racquetball	Swimming	Volleyball	Weight Training	Wrestling
Squats	*	*	*	*	*	*	*	*	*	*	*	*	*	*
KMD		X								X			X	
RWF							X		X					
DWH		X			X									
CAH							X						X	X
JMH		X												
SRJ	X										X		X	
JDL							X				X		X	
JBL													X	
JAS		X											X	
DRS		X			X									
AES							X			X				
RBT									X					
Plyometrics		*	*	*	*	*	*	*	*	*	*	*	*	*
JEB		X												
WBC									X				X	
CTD		X								X			X	
PJF		X							X	X				
DCG													X	
JWH							X		X					
TJH				X			X							
KDJ	X				X								X	
CML							X	X						
PTM	X		X			X								
CCS	X	X										X		
MHW									X					

Note: Activities listed were engaged in more than one time per week during the study period and for the quarter preceding the study. No subject had trained leg strength or power for at least one quarter preceding the study period. No subject exceeded the aerobic or leg strength training limits of the study.

## APPENDIX E

### Individual Data for Squat Group

Subject	Age	Height (in)	Pre Wt (lbs)	Post Wt (lbs)	Pre 60 R	Pre 60 L	Post 60 R	Post 60 L	Pre 180 R	Pre 180 L	Post 180 R	Post 180 L	Pre 240 R	Pre 240 L	Post 240 R	Post 240 L	Pre VJ (in)	Post VJ (in)	Pre SR (sec)	Post SR (sec)
KMD	22	75	181.5	186.0	211	219	240	240	165	174	183	158	143	127	156	140	19.5	21.0	.523	.556
RWF	25	69	178.5	173.0	168	191	217	204	130	126	152	152	119	98	141	131	13.0	14.0	.621	.578
DWH	23	70	176.5	176.0	195	176	198	178	117	102	126	106	72	66	98	66	13.5	13.5	.567	.544
CAH	22	71	205.0	196.0	293	268	318	314	220	198	241	260	195	186	181	185	21.0	23.5	.477	.436
JMH	22	75	188.0	190.0	261	278	345	345	242	230	235	245	223	227	223	200	23.0	26.5	.444	.470
SRJ	20	68	167.5	169.0	235	225	242	254	148	140	171	174	98	123	140	158	18.5	19.5	.518	.505
JDL	28	77	182.0	179.0	236	209	238	218	160	150	180	159	107	136	117	120	16.0	17.5	.634	.607
JBL	29	77	238.0	239.0	319	326	350	350	273	268	290	275	233	219	240	230	18.5	18.0	.588	.600
JAS	23	68	155.0	155.5	160	153	205	200	145	100	164	135	77	73	159	114	15.0	17.0	.567	.574
DRS	22	71	154.0	156.0	211	234	198	212	149	162	161	175	124	142	142	150	21.5	22.5	.455	.430
AES	25	69	166.0	166.0	186	169	196	203	130	125	145	137	133	108	147	148	14.0	16.5	.614	.543
RBT	20	68	185.5	189.0	225	240	264	300	160	169	175	186	148	132	145	154	17.0	21.0	.496	.461

APPENDIX F

Individual Data for Plyometric Group

Subject	Age	Height (in)	Pre Wt (lbs)	Post Wt (lbs)	Pre 60 R	Pre 60 L	Post 60 R	Post 60 L	Pre 180 R	Pre 180 L	Post 180 R	Post 180 L	Pre 240 R	Pre 240 L	Post 240 R	Post 240 L	Pre VJ (in)	Post VJ (in)	Pre SR (sec)	Post SR (sec)
JEB	29	77	188.0	195.0	214	216	236	204	164	175	180	154	138	154	144	143	17.5	21.0	.570	.555
WBC	21	69	167.5	171.5	243	224	257	280	187	153	177	176	136	115	158	125	17.5	17.5	.499	.508
CTD	24	72	151.0	154.0	225	215	230	234	170	159	200	175	144	143	168	165	19.0	21.0	.486	.473
PJF	22	76	194.5	190.0	205	222	231	238	153	186	189	191	145	164	161	154	14.5	17.0	.600	.595
DCG	22	71	196.5	199.0	260	270	290	290	180	178	188	133	170	130	152	122	19.5	20.0	.491	.513
JWH	21	76	178.5	178.5	234	231	284	260	196	191	243	239	163	155	210	191	16.5	18.5	.512	.488
TJH	23	68	148.0	147.0	230	208	191	191	143	142	152	141	106	111	148	105	17.0	17.5	.549	.499
KDJ	22	69	163.5	166.0	205	203	198	206	132	133	150	145	106	94	75	118	17.0	19.0	.587	.589
CML	20	74	205.5	199.0	288	277	280	263	234	214	221	211	207	203	184	181	22.5	21.0	.617	.579
PTM	21	72	168.5	154.5	204	246	180	169	137	143	110	128	97	110	68	90	12.5	12.5	.576	.591
CCS	21	76	206.5	205.0	247	259	250	252	203	221	205	210	177	189	170	200	18.0	20.5	.501	.516
MHW	23	72	158.5	158.5	243	217	282	245	135	134	182	184	128	101	161	147	13.5	16.0	.555	.560