# THE COMPARATIVE EFFECTS ON VERTICAL JUMP OF THREE DIFFERENT DEPTH JUMP PROGRAMS

by

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# ABSTRACT

The purpose of this study was to investigate which factor in depth jumping, landing momentum or landing velocity, is the more effective in improving vertical jump.

Three depth jump training conditions were utilized: a high velocity, high momentum condition in which the subjects (n=10) jumped unloaded from their individual optimum heights (the height where their rebound height equaled the height jumped from); a low velocity, high momentum condition in which the subjects (n=10) jumped wearing weight jackets that weighed 15% of their body weight from heights that resulted in their landing momenta being equal to their calculated landing momenta had they been performing the high velocity, high momentum conditions; and a medium velocity, low momentum condition in which the subjects (n=8) jumped unloaded from heights midway between their optimum heights and their calculated jump heights had they been performing the low velocity, high momentum condition.

Twenty-eight male members of University of British Columbia athletic teams volunteered as subjects. Each team was divided equally between, but individual team members assigned randomly to, each of the three experimental conditions.

The depth jump programs consisted of four sets of eight jumps twice a week for the first three weeks and five sets of eight jumps three times a week for the last three weeks.

All subjects were tested at the beginning, middle and end of the study on the Sargeant Jump Test, Standard Depth Jump Test (performed from an 18 in platform). Knee Extension Strength Test and Plantar Flexion Strength Test.

Multivariate analysis of variance revealed that performance of all three training conditions resulted in improvement of vertical jump, standard depth jump and plantar flexion strength (all significant at the .01 level) and that

there were no significant differences between the conditions in improvement on these measures. No significant improvement was seen in knee extension strength in any of the conditions. Pearson Product Moment Correlation of the four variables showed that there were strong correlations between sargeant jump and standard depth jump (significant at the .01 level) and between knee extension strength and plantar flexion strength (significant at the .05 level) but no significant correlations between the jump and strength measures.

At the end of the study a force platform was utilized to record the reaction force characteristics of eight subjects while they performed jumps under each of the three training conditions.

Multivariate analysis of variance of the data revealed significant differences between the conditions on the impulse variables and no significant differences between the conditions on time or force variables. Post-hoc Newman-Kuels multiple comparison tests revealed that the impulses of the subjects when jumping under the low velocity, high momentum condition were significantly greater (at the .05 level) than the impulses recorded when the subjects were jumping in the other two conditions (which were not significantly different from each other).

The results of this study did not indicate clearly which factor in depth jumping, landing momentum or landing velocity, was more effective in improving vertical jump.

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# Chapter 1

## INTRODUCTION

Plyometrics is a form of power training (Wilt, 1975; Verhoshanskiy, 1966, 1967) which utilizes the principal of prestretching the muscles to attain greater developed force and speed of contraction of those muscles (Marey, Demeny, 1885; Cavagna, Dusman, Margaria, 1968; Thys, Faraggiana, Margaria, 1972). The effect is a summation of forces caused by storage of energy in the muscles' series elastic component and by the ability of the contractile element to develop a greater force after being stretched (Cavagna, Dusman, Margaria, 1968). More force is developed when the muscle is stretched faster, when the muscle is stretched to a greater length and when the positive work follows more quickly after the stretch, (Cavagna, Dusman, Margaria, 1968; Asmussen, Bonde-Petersen, 1974; Wilt, 1975).

It has been found that the greater forces developed by prestretching muscle result in a training effect whereby the muscle gains strength and the nerve-muscle apparatus becomes more reactive with resulting increase in power (Verhoshanskiy, 1966, 1967).

Depth jumping is a plyometric exercise which has been developed to increase leg power and as such may be of value to most athletes. It has been recommended that depth jumps be performed with resistance not in the form of weights but as an increase in the height from which the jump is made. Ranges have been found for maximum increase in reactive ability and strength and these are 0.75 m and 1.15 m respectively (Verhoshanskiy, 1967). Beyond the upper limit damage is done to the jumping skill and no positive training effect is seen (Verhoshanskiy, 1967, Wilt, 1976). There does not appear to have been any investigation into the effects of loading during depth jumping although it has been stated that overloading is an undesirable activity

(Verhoshanskiy, 1967).

## STATEMENT OF THE PROBLEM

The purpose of the investigation is to compare the effects of three depth jumping programs on a vertical jump.

## DEFINITIONS

Plyometric Exercise - an activity which increases power stretching the muscles immediately prior to contraction.

Depth Jump - a plyometric exercise which emphasizes an explosive take-off after landing from a previous drop. Depth jumping is believed to improve the reactive ability of the nerve-muscle apparatus.

Loading - the mass of the subject plus any external mass acting on the subject.

Amortisation Phase - is the part of the depth jump where the legs are slowing the descending body mass.

Positive Work - done when the muscles are shortening in length.

Negative Work - done when the muscle resists while being stretched.

Eccentric Contraction - when the muscle is trying to shorten while being stretched. Negative work is done.

Concentric Contraction - when the muscle is shortening during contraction.

Isometric Contraction - when the muscle is trying to shorten but is held at a constant length.

Isokinetic Contraction - when the muscle is contracting concentrically but at a constant speed.

Voluntary Contraction - the response of a muscle to a stimulus evoked by a conscious decision of the individual.

Reflex Contraction - the response of a muscle to a stimulus evoked by a nerve path through the spinal cord. There is no conscious control over the reflex.

Myotatic Reflex - the response of an innervated muscle to stretch. A stretch reflex.

Elastic Recoil - when the series-elastic components of the muscle, after being stretched, release their stored energy by shortening.

Counter-movement - a preparatory movement in the direction opposite to that of the final movement.

Optimum Height - where the height of the rebound jump equals the height jumped from. Optimum height can also be found by determining from which height the time on the ground is minimum with the amortisation phase taking the same amount of time as the rebound phase. All these things occur during a jump from optimum height.

## HYPOTHESES

1. Depth jump training will produce a significant increase in jumping ability.

   Rationale: Since performance of the vertical jump and depth jump require leg power an increase in leg power as a result of depth jump training should result in an increase in vertical jump.

2. Depth jump training will produce a significant increase in leg strength.

   Rationale: Since depth jump training improves leg strength there should be resultant increases on the leg strength tests.

3. The low velocity, high momentum group will produce a significant leg strength increase over the two other groups.

   Rationale: Depth jump training increases leg muscle strength and the low velocity, high momentum (overload) group will be jumping with greater relative mass than the two unloaded groups and so will have a greater resistance to work against in the rebound phase. This should cause a larger increase in static leg strength.

4. The high velocity, high momentum group will produce a significant increase in jumping ability over the medium velocity, low momentum group which will produce a significant increase in jumping ability over the low velocity, high momentum group.

Rationale: Depth jump training develops increased power by apparently increasing the reactive ability of the nerve-muscle apparatus. It has been discovered that more force is developed in the muscle if the stretch is faster and the positive contraction occurs immediately following the eccentric contraction. This may be the factor that improves reactive ability. The high velocity, high momentum group jumping from optimum height will attain the greatest velocity and will spend the least time on the ground so should be able to jump higher than the other groups. The medium velocity, low momentum group jumping from sub-optimum height will attain a greater velocity than the low velocity, high momentum group and should improve their reactive ability to a higher level, the result being more jumping ability.

## DELIMITATIONS

1. The subjects for this study will be members of University of British Columbia men's athletic teams.
2. The effects of the depth jumping programs will be assessed over a six week period.
3. The effects of the depth jump programs will be measured by the Sargeant Jump Test, a Standard Depth Jump Test and cable tensiometer tests of

Knee Extension and Plantar Flexion Strength.

## LIMITATIONS

1. The investigator will have no control over the subjects' activities outside the testing stituation.
2. The subjects will not necessarily have the same number of practice hours per week at their respective sports.
3. Motivation of the subjects to provide maximum effort in the program will not be able to be assessed.
4. In testing, the height of the vertical jumps will be a measure of hand displacement and therefore not a completely true measure of centre of gravity displacement.

## SIGNIFICANCE OF THE STUDY

Depth jump training is beneficial in developing leg power and does so by utilizing muscle stretch prior to positive muscle contraction. The act of prestretching the muscle is believed to allow greater forces of contraction through momentary storage of energy in the muscle's series elastic elements and increased force of contraction by the muscle's contractile elements. Physiological studies have determined that muscle forces are affected by the velocity of the stretch, that is the faster the stretch the greater the muscle force created. It has been discovered that there is an optimum jump height where maximum reactive ability is developed and beyond which dynamic strength is increased but reactiveness decreases. The reason for this seems to be that the momentum of the drop becomes too great for the muscles to dissipate and the switch to positive work occurs too slowly to aid in increasing reactive ability. There are, however, no published studies investigating the effects of overloading during depth jumping. Overloading changes the quality of the jump by increasing momentum if the drop is the same distance as for an unloaded jump. If the momentum is to be kept the same as in the unloaded jump the velocity must be decreased by decreasing the height of the drop. This study will attempt to establish which one of the factors, momentum or velocity, is predominant in enhancing jumping ability.

# Chapter 2

## REVIEW OF LITERATURE

There have been many studies reported on the effect of training programs on vertical jump, but few on the effects of depth jumping on vertical jump. There have been, to the investigators knowledge, only two scientific studies (Keohane, 1977; Scoles, 1978) completed on depth jump training and another that reported the effects of bounding on running speed. There have been several articles, mostly empirical, that dealt with depth jumping but they did not offer evidence of a completed training study. Therefore, scientific training studies that have had vertical jump as a parameter will be examined.

### Studies on Vertical Jump

Studies that have used vertical jump as a parameter are legion and have utilized many different methods of training. Programs have been followed using weight training, isometric exercise, isokinetic exercise, isotonic exercise, jumping exercise, rope jumping, stair running and trampolining.

Capen (1950), Garth (1954), Ness and Sharos (1956), Brown and Riley (1957), Knudtson (1957), Chui (1960), Luitjens (1969), Darling (1970), Tanner (1971), Staheli, Roundy and Allsen (1975), Thorstensson (1976), and Silvester (1976) found weight training effective in increasing vertical jump. Capen (1950) found significant increases in vertical jump, standing long jump and leg strength measures during a 12 week weight training program by a group of male college students. Significant gains in vertical jump were reported by Garth (1954) in a group of college basketball players involved in a six week weight training study. A program of deep knee bends and toe raises with weights was reported by Ness and Sharos (1956) to increase leg strength and vertical jump. Brown and Riley (1957) reported significant training effect in vertical jump, leg strength and plantar flexion strength by a group of college basketball players involved in a weight training program. Similar results in leg strength and vertical jump gains were reported by Knudtson (1957) using female basketball players and by Chui (1960) using college men. Luitjens (1969) used two training regimens, weight training and Exer-Genie, and found significant gains for, and insignificant differences between the two groups in explosive leg power and leg strength. Darling (1970) also used two training conditions, deep knee bends and toe raises, and found significant increases in vertical jump with insignificant differences between groups. Tanner (1971) found that a group performing one set of RM deep knee bends showed significant increases in vertical jump as did a group doing a similar set at 50-60% RM. Again no significant differences were found between groups. Staheli et al (1970) used three training groups and one control group to investigate the effects of isokenetic and isotonic exercise on leg strength, vertical jump and thigh circumference. The conditions were power rack, leg press and squats and all showed significant increases in all measurements but displayed no significant differences between groups. Thorstensson (1970) found a regimen of squats and vertical jumps resulted in increases in leg strength (measured by maximum squat), vertical jump, standing broad jump and two legged isometric leg strength. Four training conditions were implemented by Silvester (1976) to compare the effects of variable resistance and free weight training on leg strength, vertical jump, and thigh circumference. Two treatment groups did squats at 80% RM but one did three sets of six and the other one set of six and a second set to exhaustion. The other two conditions were use of the Nautilus Compound Machine and the Universal Dynamic Variable Resistance leg press station. All groups showed significant gains in leg strength and no gains in thigh circumference. A significant difference in hip extension strength in favor of the three sets of six squat group over the Nautilus group was obtained in all groups but the Nautilus group showed significant increases in vertical jump.

Roberts (1956), Charles (1966), Hansen (1969), and Silvester (1976) have presented evidence that weight training did not improve vertical jump. A program of forward, lateral, and heel raises, squats and curls were reported by Roberts (1956) not to improve vertical jump. Charles (1966) found no significant increase in vertical jump but a significant increase in leg strength after completion of an explosive weight training program. Hansen (1969) found that trampline or weight training either utilized individually or in combination did not produce improvement in vertical jump. The Nautilus Compound machine was found by Silvester (1976) not to produce improved vertical jump performance.

Fisher (1968), De Venzio (1969) and Tanner (1971) found that isometric exercise improved vertical jump. Fisher (1960) compared the effects of isometric exercise, weight training, Exer-Genie training and jumping with ankle spats on vertical jump. It was found that significant increases in vertical jump were experienced by all groups with no significance between group effect. De Venzio (1969) found significant improvement in vertical jump by a group performing isometric exercises and no increase in leg or back strength from either the isometric group or another group performing isotonic exercises. Tanner (1971) supported De Venzio's vertical jump results but found dynamic overloading to be significantly better method of improving jump performance. Delacerda (1969) completed a training study that failed to support isometric exercise as a means of improving vertical jump.

Fisher (1968) and Luitjens (1969) found the Exer-Genie improved vertical jump as did Delacerda (1969) although it was found that a rebound jumping program was as successful. Escutia (1971) and Testone (1972) found that isokinetic exercises performed on the Super Mini Gym increased leg strength significantly but not vertical jump. Van Oteghen (1973) used women in two training conditions of isokinetic exercise. Both groups performed leg presses, one taking four seconds for each repetition and the other group two seconds. Three sets of ten were completed in each session. At the end of eight weeks both groups showed significant increases in leg strength and vertical jump measures with the slow group showing a greater and significant difference in the leg strength. Copeland (1977) investigated the effects of isokinetic power training on a group of women's vertical jump. An Orthotron Exercise System was utilized and set at a releasing speed of 250 deg/sec. A control group and training group were formed with equal representation of good (high) and poor (low) jumpers. The trained poor jumpers showed significant increases in vertical jump while the trained jumpers did not.

The effect of the use of ankle spats has been investigated by Anderson (1961), Fisher (1968) and Boyd (1969). Anderson (1961) found that the experimental group improved significantly in vertical jump, 300 yard run and agility tests. Fisher (1968) found ankle spats effective in improving vertical jump but Boyd (1969) found that there was no significant difference between his control and experimental group even though the experimental group showed significant improvement in jumping ability.

Isotonic exercises using body weights were found to be effective in increasing vertical jump in young males by Gibson (1961). Blucher (1965) found them to be ineffective in improving the jumping performance of college women and also reported insignificant correlations of leg strength with vertical jump or running speed. Jones (1972) found ankle exercises ineffective in improving the jumping ability of young boys although plantar flexion strength improved.

Marino (1960) found rope skipping improved vertical jump as did Fisher (1968) when skipping with ankle weights. Quarles (1967) failed to support rope skipping as a method for improvement of vertical jump but found that stair running improved leg power.

Tanner (1971) and Delacerda (1969) found jumping exercises effective in improving jumping ability. Escutia (1971) with volleyball players supported these findings but a study by Roberts (1956) with basketball players failed to support this.

Allen (1962) found trampoline training combined with rope skipping improved hip flexion strength. However, Brees (1961) and Hansen (1969) found trampoline training ineffective in improving vertical jump.

Keohane (1977) investigated the effect of depth jump training on vertical jumping ability on and off the ice using a group of figure skaters as subjects. It was found that a depth jumping program resulted in significant improvement in vertical jump both on and off the ice and that the two parameters were significantly positively correlated. Scoles (1978) employed flexibility and depth jumping groups and neither showed significant gains in vertical jumping or standing long jump.

Depth Jumping.

Depth jumping is a new form of training that has been developed in Europe, primarily in the Soviet Union. Because of the problems of obtaining and translating material there is little literature to be had on the subject in North America. There have been several articles published after translation from Russian and there are previous investigations of underlying principles that were completed in Western Europe and North America. These findings will be reviewed.

Muscle Elasticity and Prestretch. There is apparently a series-elastic component in muscle that, when stretched, will momentarily store energy that can be used during a subsequent contraction of that muscle (Marey and Demeny, 1885; Fenn, 1930; Fenn and Marsh, 1935; Cavagna, Dusman, Margaria, 1968; Thys, Faraggiano, Margaria, 1972). The efficiency of this action increases the sooner the muscle stretch is followed by a concentric contraction (Asmussen and Bonde-Petersen, 1974; Cavagna et al., 1968). It has been found that running was more efficient than walking in utilizing the energy stored in the elastic component and walking is more efficient than bicycling. Marey and Demeny (1885) and Asmussen and Bonde-Petersen (1974) found that jumping with a counter-movement resulted in better performance than jumping without a counter-movement. Again Asmussen and Bonde-Petersen (1974) found that performance was enhanced by more forceful counter-movements obtained when jumping from heights of 0.233 m, 0.404 m and 0.690 m.

The forces involved in eccentric contraction and any subsequent concentric contraction are greater than those attained in a motion involving prestretch (Cavagna et al., 1968; Thys et al., 1972; Asmussen and Bonde-Petersen, 1974). Cavagna et al. (1968) found that muscles can develop more force during an eccentric contraction. Rodgers (1973) found that eccentric forces can be up to two times greater than isometric forces measured at the same muscle length. Cavagna et al. (1968) reported that when eccentric and isometric forces at the same muscle length were equal, subsequent concentric contractions resulted in more work being done by the prestretched muscle than by the isometrically contracted muscle.

Cavagna et al. (1968) also found that the contractile elements contracted with more force after prestretch and would continue to apply more force than an unstretched muscle as the velocity of contraction increased. It was also reported that the force of eccentric and concentric contractions were greater as the muscle was stretched to longer lengths.

The velocity of the muscle stretch also has an effect on the forces developed. It was found that as the speed of stretch increased the force developed increased (Fenn and Marsh, 1935; Cavagna et al., 1968) and the time of the positive contraction decreased (Thys et al., 1972; Asmussen and Bonde-Petersen, 1974).

Myotatic Reflexes. It has been reported that myotatic reflexes play a role in depth jumping (Ozolin, 1972; Wilt, 1975; Boosey, 1976; Scoles, 1978). Melvill Jones and Watt (1971) reported three responses to stimulation, two of which were determined to be reflexive in character. The first E.M.G. activity occurred about 40 msec after initial contact and resulted in no muscular reaction. A later burst of activity after 120 msec represented the working reflexive arc and resulted about 30 msec later in actual muscular response. The third response time was that of voluntary expression and took 165 msec to occur. The second reflex response was called the functional stretch reflex (FSR). Melvill Jones and Watt (1971) also found that in actual landing the FSR is inhibited and concluded that it didn't play a role in arresting downward motion on landing. It was felt that all muscular activity was preprogrammed before contact. In hopping movements, however, the FSR contributed to the upward motion, particularly at a frequency of 2.06 hops/sec. This frequency had the subjects on the ground for 263 msec/hop and it was found that efficiency was not as good at hopping frequencies either smaller or larger than the favoured value. It was reported that a reflexive pattern initiated by the effect of free fall on the vestibular apparatus could play a part in controlling the hopping action.

Principles of Depth Jumping. Verhoshanskiy (1966) stated that training only with weights or jump programs did not result in expected results in performance. It was felt that the reason for this was that either program did not develop the reactive ability of subjects and the idea was promoted that a form of exercise that developed this reactive ability should be undertaken. It was put forward that depth jumps be utilized in this direction and that combined with weight training they would result in good performances.

In another article Verhoshanskiy (1967) reinforced the idea that further improvement in performances would come from improving the reactive ability of the nerve-muscle apparatus and this could be done by employing "shock" methods. Namely by depth jumping. It was felt that by combining jumping for depth with regular training, maximum results could be obtained in minimum time.

Wilt, Cerutti, Embling, Toomsalu, Pross, McGuire and Schubert (1974) stated that improvement in the relationship between maximum strength and explosive power could be brought about by employing plyometric drills. It was thought that these drills relied on their success due to the prestretching of the muscles in the amortisation phase of the movements, allowing the muscle to contract with greater force. Zanon (1974) recommended that plyometric exercise should employ as short an amortisation period as possible and that the pattern of the movement should remain as unaltered as possible.

Lefroy (1974) recommended rebound jumping as an activity to develop explosive power and emphasized that the landing and jump should be one motion with no hesitation between the movements.

Ecker (1975) felt that plyometric exercises were the best exercise for developing successful sprinters.

Wilt (1975; 1976) stressed that plyometric exercises were a benefit in improving the relationship between strength and power. It was stressed that plyometric exercises relied on eccentric contraction of the stretched muscles to develop greater force and speed of movement during the concentric contraction. Wilt felt that the eccentric contraction also allowed the muscle to use a myotatic or stretch reflex contraction during the concentric contraction which aided in developing more force.

Boosey (1976) recommended depth jumps for training and stressed a fast take-off after landing. It was felt that the falling body mass stimulated the muscles to work, and it was unnecessary to implement extra loading.

Timing of the Jumps. Three factors play an important role in depth jumping and they are voluntary expression of force, elastic recoil and stretch reflex contraction (Ozolin, 1973; Boosey, 1976). Because of these factors the timing of the jump is of the utmost importance.

The amortisation phase of the jump should be as short as possible and equal in time to the extension phase (Katchajov, Gomberaze and Revson, 1976).

The faster the landing and take-off, the more efficiently force can be stored and transmitted by the series-elastic components of the muscle (Wilt et al., 1974; Asmussen, Bonde-Petersen, 1974; Wilt, 1975). Greater landing speed also allows the contractile elements to shorten with greater force during the concentric phase of contraction. These circumstances must then combine with the FSR which operates most effectively when 200-263 msec is spent on the ground during the jump.

The legs must be bent at 130-135 deg (Ozolin, 1972) on first contact to prevent a damaging jolt but care must be taken to prevent too great an absorption phase. The trunk and arms must be held in the proper attitude and carry out the proper actions as they can contribute up to 22% of the jump force (Luhtanen and Komi, 1978).

<u>Optimum Height</u>. Asmussen and Bonde-Petersen (1974) reported that maximum reaction force and jump height were obtained in their study when depth jumps were performed from 0.404 m. The rebound jump and jump height were approximately equal at this level. Jumps from 0.233 m and 0.690 m were not as forceful as those from 0.404 m.

Verhoshanskiy (1967) states that jumps from 0.75 m resulted in maximum speed of the muscles in switching from negative to positive work and that jumps from above 1.10 m resulted in harm being done to the jump skill.

Katchajov, et al. (1976) found that rebound height in a depth jump reached a maximum at 0.80 m. At this height amortisation and take-off phases were approximately equal and at their minimum in duration.

<u>Repetition in Depth Jump Training</u>. Verhoshanskiy (1967) states that 40 jumps twice a week is a reasonable program because it takes longer to recover from this type of work. He suggests sets of 10 with running and stretching exercises between.

Zanon (1974) suggests six to 10 sets of five to eight repetitions with 10 to 15 minute rests between the sets. Lefroy (1974) recommends five short work periods of five to 15 seconds duration with a minute rest between them.

Keohane (1977) used five exercises with a total of 15 sets and 80 repetitions, and Scoles (1978) used a program of 20 jumps per session.

<u>Progression and Overload in Depth Jumping</u>. Verhoshanskiy (1967) states that it is preferable to create overload by increasing jump height leaving the repetitions and weight load the same. Extra mass will increase the time spent on the ground and more repetitions will result in an endurance workout. The maximum height, of course, should not exceed 1.10 m.

Introduction to Athlete's Program. Verhoshanskiy (1966) noted that as athletes became more advanced their training fails more and more to bring their performances in line with projected expectations. It is felt that this is due to the fact that skill practice and weight training fail to increase and sometimes decrease the athlete's reaction ability. Skill practice and weight training can cause large improvements, particularly among novices, and Verhoshanskiy ranks athletes on that criteria. Class III athletes, novices whose strength is low, do a general developmental strength and jump program with moderate loading. Class II athletes, intermediate in experience and strength, use weights at 75-90% maximum and form a base for the explosive activities desired. Class I and Master of Sport athletes, who are national and international level competitors, direct their efforts to improving reaction ability in the nerve-muscle apparatus through depth jumping and performing weights at 100% maximum.

Verhoshanskiy (1966) feels that athletes should start at their indicated level and then work towards the top level before doing depth jump training.

Summary. From the literature at hand all weight lifting except that employing the Nautilus Compound machine were effective in improving vertical jump performance. (Capen, 1950; Garth, 1954; Ness and Sharos, 1956; Brown and Riley, 1957; Knudtson, 1958; Chui, 1960; Luitjens, 1969; Darling, 1970; Tanner, 1971; Staheli et al., 1975; Thorstsson et al., 1976; and Silvester, 1972). Isometric exercises were found to be effective in improving jumping ability by Fisher (1968), De Venzio (1969) and Tanner (1971) and ineffective by Delacerda (1969).

Isokinetic exercises were found to increase vertical jump (Fisher, 1968; Luitjens, 1969; and Delacerda 1969) by using the Exer-Genie and by Van Oteghen (1973) using the Compensator leg press machine. Escutia (1971) and Testone

(1972) found the Super Mini Gym ineffective in improving vertical jump and Copeland (1977) found the Orthotron Exercise System effective in improving vertical jump for only those classified initially as poor jumpers. Use of ankle weights improved jumping ability in studies by Anderson (1961) and Fisher (1968), and lead to ambiguous results by Boyd (1969).

Blucker (1965) and Jones (1972) found isotonic exercises unsuccessful in improving vertical jump but Gibson (1961) obtained results counter to those findings. Marino (1960) and Fisher (1968) found skipping conductive to jumping increases. Quarles (1967) did not support these results but concluded that stair running improved leg power.

Delacerda (1969), Escutia (1971), and Tanner (1971) found that repeated jumping exercises were successful. Roberts (1956) found that they did not enhance jumping ability. Trampoline training was found to be ineffective in improving leg power by Brees (1961) and Hansen (1969) and effective by Allen (162). Keohane (1977) concluded that depth jump training was successful in improving vertical jump but Scoles (1978) failed to support these findings.

Of the methods reviewed weight training seems to have been the most consistent in improving vertical jump.

Depth Jumping is a form of training which utilizes the physiological effects of muscle stretch to increase force during the following concentric contractions. The training program increases the reactive ability of the athlete by emphasizing a fast explosive landing and take-off from a predetermined height. The height chosen allows the amortisation and extension phases to be equal in duration and results in a rebound height matching the initial jump height.

Depth jumping is designed for advanced athletes who have undertaken previous strength training. Overload is created by increasing the height jumped from, not by weight loading or increasing the number of repetitions.

# Chapter 3

# METHODS AND PROCEDURES

## Subjects

Thirty-eight male athletes from university teams volunteered to take part in the study. Three groups were formed with equal team representation in each group but with random selection as to which group any particular individual was assigned. One group was an overload group, another was a normal load group jumping from sub-optimum height and the third was a normal load group jumping from its optimum height.

## Groups

The normal load group jumping from their optimum heights had high momenta and high velocities of landing.

The overload group had high momenta but low velocities of landing. The landing momenta of the subjects were equal to the landing momenta they would have attained if they were in the normal load optimum height group.

The normal load group jumping from sub-optimum height had low momenta and moderate velocities of landing.

The subjects jumped from a height that was midway between their optimum height and the height they would have jumped from had they been in the overload group.

## Time and Duration of the Study

The study took place over a six week period and formed another exercise period in addition to normal practices.

There were two training sessions per week for the first three weeks and three times per week for the last three weeks.

# TESTS

Three test sessions were held: pretest, at the beginning of the study; midtest, at the end of the third week; and post test, at the end of the study. All subjects were tested on the Sargeant Jump Test, a Standard Depth Jump Test and with a cable tensiometer to determine knee extension and plantar flexion strength. Their weight was measured during the pretest and their optimum height (and therefore momentum) for a depth jump was determined at each testing.

Prior to the pretest subjects attended a familiarization session where they were introduced to the tests and allowed to practice them and were also taught how to execute a proper depth jump.

During a test period reaction force readings were collected by use of a Kistler type 9261A force plate, Kistler type 5001 Charge Amplifier and a M.F.E. 3 channel 100 mm recorder. The data included readings taken for overload, normal load at sub-optimum and normal load at optimum depth jumps. An analysis of reaction force data was done comparing the peak forces, impulses and times between the three jump conditions.

## Sargeant Jump Test

The subjects were first measured for their maximum vertical reach with the hand of their choice using an calibrated wall board. They then stood to the side of another calibrated board and without shuffling their feet jumped and reached as high as possible making contact with the board at the apex of their jump.

## Standard Depth Jump Test

The subjects jumped down from an 18 in height, executed a two footed jump and reached as high as possible. The height attained was measured as in the Sargeant Jump Test.

Cable Tensiometer Tests

The strength of the knee extensors was determined at a 115 deg angle at the knee joint. The plantar flexion strength was determined with the ankle joint at a 90 deg angle.

## PROCEDURES FOR THE DEPTH JUMPING PROGRAMS

The program was preceded by individual warm-up sessions comprised of each subject's normal routine.

The program itself was performed as four sets with eight repetitions in each set for the first three weeks. The second three weeks entailed a program of five sets of eight repetitions three times a week. Each repetition followed without delay the previous one with one to two minutes rest between each set.

Two test groups, the overload group and the normal load group jumping from optimum heights, had the same momentum of landing, the difference being that the overload group had greater mass and less velocity while the optimum height group had less mass but greater velocity. The third group had the same mass as the optimum group but had a smaller velocity and therefore had a lower landing momentum.

This meant that the overload group jumped from lower heights than the normal load groups and wore weight jackets that had a weight 15% of the body weight.

The normal load at sub-optimum subjects jumped from a height midway between the optimum determined in testing and the height they would have jumped from if they had been assigned to the overload group.

The normal load at optimum height subjects jumped from their optimum height as determined during testing.

The various training heights were determined by calculating the velocity that a free falling object would attain when released from each of the heights in the training range. Taking these heights as optimum training heights, the overload training heights were calculated by dividing the optimum height velocities by 1.15 (see appendix B) and matching the resulting figure with the height displaying the nearest velocity (Table 1). The training heights for the unloaded sub-optimum group were determined by selecting the height midway between their optimum and calculated loaded heights. The training heights are listed in Table 2.

Training heights for the subjects were altered after the midtest if there was a change in their measured optimum height. This was done in order to maintain the proposed training conditions.

Subjects were instructed to follow the principles laid down by Lefroy (1974):

1. Each jump should be a maximum effort.
2. Each set of jumps should be done quickly without pauses between jumps.
3. Each jump should be a bounce executed as quickly as possible.

## EXPERIMENTAL DESIGN

The study was a 3 x 3 factorial with repeated measures on the second factor (figure 1). The independent variables were the treatment factors with 3 levels (optimum, overload, unloaded at sub-optimum) and the time factor with three levels (pre, mid, post). Four dependent variables were measured; sargeant jump height, standard depth jump height, knee extension strength and plantar flexion strength.

Table 1

Velocities Attained In The Training Height Range

| Height (in) | Velocity (ft/sec) | Height (in) | Velocity (ft/sec) |
|---|---|---|---|
| 34 | 13.47 | 22 | 10.83 |
| 33 | 13.27 | 21 | 10.58 |
| 32 | 13.06 | 20 | 10.33 |
| 31 | 12.86 | 19 | 10.07 |
| 30 | 12.65 | 18 | 9.80 |
| 29 | 12.44 | 17 | 9.52 |
| 28 | 12.22 | 16 | 9.24 |
| 27 | 12.00 | 15 | 8.94 |
| 26 | 11.78 | 14 | 8.64 |
| 25 | 11.55 | 13 | 8.33 |
| 24 | 11.31 | 12 | 8.00 |
| 23 | 11.08 | | |

Table 2

Training Heights

| Optimum Height (in) | Loaded Height (in) | Unloaded Sub-Optimum Height (in) |
|---|---|---|
| 34 | 26 | 30 |
| 33 | 25 | 29 |
| 32 | 24 | 28 |
| 31 | 23 | 27 |
| 30 | 23 | 26 |
| 29 | 22 | 25 |
| 28 | 21 | 24 |
| 27 | 20 | 23 |
| 26 | 20 | 23 |
| 25 | 19 | 22 |
| 24 | 18 | 21 |
| 23 | 17 | 20 |
| 22 | 17 | 19 |
| 21 | 16 | 18 |
| 20 | 15 | 17 |
| 19 | 14 | 16 |
| 18 | 14 | 16 |
| 17 | 13 | 15 |

The force plate analysis was 1 x 3 factorial with repeated measures on the second factor. The independent variables were the treatment factors with 3 levels (optimum, overload and unloaded at sub-optimum) and the group factor with one level. Eleven dependent variables were measured; landing force, dip force, jump force, total impulse, landing impulse, jump impulse, half jump impulse, total time, landing time, jump time and half jump time.

Figure 1

Experimental Design

| Groups | Pre | Mid | Post |
|---|---|---|---|
| Optimum | | | |
| S 1 | | | |
| . | | | |
| . | | | |
| . | | | |
| 10 | | | |
| Loaded | | | |
| S11 | | | |
| . | | | |
| . | | | |
| . | | | |
| 20 | | | |
| Unloaded sub-optimum | | | |
| S21 | | | |
| . | | | |
| . | | | |
| . | | | |
| 28 | | | |

## STATISTICAL TREATMENT

A 3 x 3 factorial analysis of variance with repeated measures on the second factor was performed on the four dependent variables using the program BMV:P2V (Halm, 1974). Each hypothesis was tested at an alpha level of .05.

The Pearson Product Moment Correlation was used to determine the magnitude of the linear relationship between the dependent variables for each training program during each testing session using the program U.B.C. Simcort (Le, 1974) and were tested at the .05 level to determine if they were significantly different from zero.

For the analysis of the force platform data a 1 x 3 factorial analysis of variance with repeated measures on the second factor was performed on the eleven dependent variables using the program BMD:P2V (Halm, 1974) and tested for significance at an alpha level of .05. Post-hoc Newman-Kuels multiple comparison tests were administered to those variables which displayed significant differences to find where the differences actually were. They were tested at the .05 level.

# Chapter 4

# RESULTS AND DISCUSSION

Thirty-eight subjects volunteered to take part in this study and were pretested with the Sargeant Jump Test, Standard Depth Jump Test, Knee Flexion Strength Test and Plantar Flexion Strength Test. Their optimum depth jump height was also determined at this time. Ten subjects did not complete the study as three suffered injuries which precluded further training and seven others withdrew through personal choice. Three subjects were lost from the optimum group, three from the overload group and four from the sub-optimum, unloaded group. Eight subjects participated in the force plate analysis of the three training conditions.

The results of this investigation and the discussion of the results are divided into two sections. The first section deals with the effects of depth jump training on vertical jump, depth jump, leg extension strength and plantar flexion strength. The second section deals with the force platform analysis of the three depth jump training conditions.

## Results: The Effect of Vertical Jump Training on Sargeant Jump, Standard Depth Jump, Knee Extension Strength and Plantar Flexion Strength.

The following results deal with the major purpose of this study, which is to investigate the effects on vertical jump of three six week depth jump training programs.

The observed cell means for the optimum, loaded and unloaded sub-optimum groups are presented in Table 3. Table 4 shows the trial means for all subjects and also displays the standard deviations.

Tables 5 through 11 contain the analysis of variance and summaries of trends.

Table 3

Observed Cell Means

| Group | Dependent Variable | Pre | Mid | Post |
|---|---|---|---|---|
| Optimum | S.J. (in) | 22.80 | 24.80 | 25.40 |
| | S.D.J. (in) | 24.00 | 25.60 | 26.20 |
| | K.E. (lb) | 219.50 | 218.00 | 220.50 |
| | P.F. (lb) | 257.40 | 312.70 | 331.60 |
| Loaded | S.J. (in) | 21.70 | 24.00 | 24.40 |
| | S.D.J. (in) | 22.40 | 24.80 | 25.10 |
| | K.E. (lb) | 233.30 | 238.40 | 246.20 |
| | P.F. (lb) | 244.20 | 305.70 | 344.70 |
| Unloaded | S.J. (in) | 23.25 | 24.50 | 24.75 |
| Sub-Optimum | S.D.J. (in) | 23.88 | 25.25 | 26.00 |
| | K.F. (lb) | 250.88 | 268.50 | 256.50 |
| | P.F. (lb) | 251.50 | 321.00 | 363.125 |

Table 4

Observed Trial Means

| Trial | Measure | Sargeant Jump (in) | Depth Jump (in) | Knee Extension (lb) | Plantar Flexion (lb) |
|---|---|---|---|---|---|
| Pre | $\bar{X}$ | 22.54 | 23.39 | 233.39 | 251.00 |
| | S.D. | 2.56 | 2.53 | 41.67 | 49.26 |
| Mid | $\bar{X}$ | 24.43 | 25.21 | 239.71 | 312.57 |
| | S.D. | 2.74 | 2.86 | 38.21 | 40.25 |
| Post | $\bar{X}$ | 24.86 | 25.75 | 239.96 | 345.29 |
| | S.D. | 2.69 | 3.01 | 41.55 | 57.89 |

Observation of Table 5 reveals that all groups improved significantly in the sargeant jump over the six week period. This is indicated by the trials row where F is 55.78. Critical F for 2 and 50 deg of freedom is 3.18 at the .05 alpha level and 5.06 at the .01 alpha level (Ferguson, 1959) so the trials effect is highly significant with a P of .001. It can also be seen that there were no significant differences between the groups in improvement. Table 6 indicates that the improvements were significantly linear and quadratic in nature. Critical F values for 1 and 25 deg of freedom are 4.24 at the .05 level and 7.77 at the .01 level. The F values for the linear and quadratic effects are 62.95 and 30.07 respectively so both are highly significant.

Table 7 shows that standard depth jump increased significantly during the study and there was no significant differences between the groups (F 48.19, P .001). Again, as for the sargeant jump, there are significant linear (F 64.81, P .001) and quadratic (F 12.39, P .001) trends as seen in Table 8.

Table 9 indicates that there are no significant training effects for knee extension strength. The critical F at the .05 level is 3.18 but the knee extension F is only .82 and must exceed critical F to be significant.

Table 10 shows that plantar flexion strength improved for all groups equally. This can be seen by the F value for the trials effect (F 59.99, P .001) which indicates that all groups improved over the training period and by the group x trials interaction which is insignificant (F .86, P .492). Significant linear and quadratic trends are seen in Table 11 with the linear F being 93.19 (P .001) and the quadratic F 4.82 (P .038).

Tables 12, 13 and 14 present the correlation coefficients for each group calculated between each dependent variable for each test period. It can be seen that the only significant correlations occur between sargeant jump and depth jump and between knee extension and plantar flexion strength. For all subjects the correlation coefficient for sargeant jump and standard depth jump at the pretest was .89, at the midtest .91 and for the posttest .91 (all significant at the .01 level). The knee extension and plantar flexion strength correlation coefficients at pre, mid and posttest were .62 (significant at the .01 level), .39 (significant at the .05 level) and .49 (significant at the .01 level).

Hypotheses. The first hypothesis states that as a result of depth jump training there is a significant increase in jumping ability for all test groups. This hypothesis is supported since all groups have shown significant increases at the.01 level in the Sargeant Jump Test and the Standard Depth Jump Test.

The second hypothesis states that as a result of depth jump training the test groups show a significant increase in the leg strength test. This hypothesis is partially supported as all groups showed significant gains at the .01 level in the plantar flexion strength test but no significant change in the knee extension strength test (not significant at .05 level).

The third hypothesis states that the overload (low velocity, high momentum) group shows a significant leg strength increase over the two normal load groups. This hypothesis is not supported as there was no significant difference between groups on either leg strength measure.

The fourth hypothesis states that the normal (high velocity, high momentum) group jumping from optimum height shows a significant increase in jumping ability over the normal load (moderate velocity, low momentum) group jumping from sub-optimum height which shows a significant increase in jumping ability over the overload group. This hypothesis was not supported since all groups improved significantly in jumping ability but not at a rate significantly different from each other.

Table 5

3 x 3 Anova Of Sargeant Jump

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Grand Mean | 1 | 47674.95 | - | - |
| Groups | 2 | 7.87 | .38 | .688 |
| Error | 25 | 20.76 | | |
| Trials | 2 | 40.31 | 55.78 | .001 |
| Trials x Groups | 4 | 1.10 | 1.53 | .209 |
| Error | 50 | 0.72 | | |

Table 6

Summary of Trend for Sargeant Jump

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials Linear | 1 | 71.14 | 62.95 | .001 |
| Error | 25 | 1.13 | | |
| Trials Quadratic | 1 | 9.48 | 30.07 | .001 |
| Error | 25 | .32 | | |

Table 7

3 x 3 Anova Of Standard Depth Jump

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Grand Mean | 1 | 51106.79 | | |
| Groups | 2 | 11.31 | .50 | .615 |
| Error | 25 | 22.81 | | |
| Trails | 2 | 41.52 | 48.19 | .001 |
| Trials x Groups | 4 | .69 | .80 | .53 |
| Error | 50 | .86 | | |

Table 8

Summary Of Trend For Standard Depth Jump

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials Linear | 1 | 75.92 | 64.81 | .001 |
| Error | 25 | 1.17 | | |
| Trials Quadratic | 1 | 7.12 | 12.89 | .001 |
| Error | 25 | .55 | | |

Table 9

3 x 3 Anova Of Knee Extension Strength

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Grand Mean | 1 | 4748819.00 | | |
| Groups | 2 | 10353.09 | 2.96 | .070 |
| Error | 25 | 3499.95 | | |
| Trials | 2 | 428.01 | .92 | .41 |
| Trials x Group | 4 | 349.00 | .75 | .56 |
| Error | 50 | 466.41 | | |

Table 10

3 x 3 Anova Of Plantar Flexion Strength

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Grand Mean | 1 | 7649681.00 | | |
| Groups | 2 | 1406.22 | 0.25 | .780 |
| Error | 25 | 5597.08 | | |
| Trials | 2 | 64615.47 | 59.99 | .001 |
| Trials x Groups | 4 | 930.28 | .86 | .492 |
| Error | 50 | 1077.10 | | |

Table 11

Summary Of Trend For Plantar Flexion Strength

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials Linear | 1 | 125333.88 | 93.19 | .001 |
| Error | 25 | 1344.93 | | |
| Trials Quad. | 1 | 3897.09 | 4.82 | .038 |
| Error | 25 | 809.27 | | |

Table 12

Pretest Correlation Coefficients

| Variables | r | Optimum | Loaded | Between |
|---|---|---|---|---|
| S.J. and D.J. | .89** | .92** | .90** | .84** |
| S.J. and K.E. | .05 | .13 | .07 | -.17 |
| S.J. and P.F. | .09 | .06 | .03 | .15 |
| D.J. and K.E. | .001 | .02 | -.16 | .16 |
| D.J. and P.F. | .09 | .21 | -.25 | .30 |
| K.E. and P.F. | .62** | .40 | .89** | .78** |

* significant at the .05 level

** significant at the .01 level

Table 13

Midtest Correlation Coefficients

| Variables | r | Optimum | Loaded | Between |
|---|---|---|---|---|
| S.J. and D.J. | .91** | .92** | .97** | .83* |
| S.J. and K.E. | .14 | .26 | .49 | -.24 |
| S.J. and P.F. | .13 | .24 | .28 | -.26 |
| D.J. and K.E. | .14 | .26 | .50 | -.17 |
| D.J. and P.F. | .17 | .18 | .24 | .07 |
| K.E. and P.F. | .39* | .13 | .55 | .60 |

* significant at the .05 level
** significant at the .01 level

Table 14

Posttest Correlation Coefficients

| Variables | r | Optimum | Loaded | Between |
|---|---|---|---|---|
| S.J. and D.J. | .91** | .94** | .91** | .82* |
| S.J. and K.E. | .06 | .14 | .10 | .10 |
| S.J. and P.F. | .002 | .30 | -.04 | -.36 |
| D.J. and K.E. | .07 | .17 | .19 | -.22 |
| D.J. and P.F. | -.001 | .15 | -.07 | -.11 |
| K.E. and P.F. | .49** | .46 | .71* | .11 |

* significant at the .05 level
** significant at the .01 level

Discussion

Although jumping ability increased for all groups during the study there were no observable differences in the rate of improvement of the groups. That is, no group or groups improved significantly over any other group or groups. Two conditions of landing momentum and three conditions of landing velocity were examined in this study and no significant differences were realized between the conditions when comparing change in any of the measured parameters.

The training heights are listed in Table 2. If three subjects had the same optimum height depth jump (e.g. 28 in) but were in different training groups their training heights were 28 in for the optimum height group, 21 in for the loaded group and 24 in for the unloaded at sub-optimum height group. From Table 1 the landing velocities for these heights are 12.22 ft/sec from 28 in, 10.58 ft/sec from 21 in and 11.31 ft/sec from 24 in. If all three subjects had the same body weight (e.g. 160 lb) and therefore mass (m=lb/g=160/32=5.0 slugs) then the landing momenta (mxvel of landing) would be: from 28 in, (12.22) 5=61.10 lb-sec; from 21 in, (10.58) (5(1.15))= 60.84 lb-sec; and from 24 in, (11.31) 5=56.55 lb-sec.

Perhaps the momenta and velocities used in this study were too similar to each other for any differences to be seen with the number of subjects used.

This study has shown that depth jumping increases jumping ability. This indicates that the jump take-off velocity increased which indicates that an improvement in leg power was likely and supports Verhoshanskiy (1966, 1967, 1974) who stated that depth jumping is an effective method of improving leg power. This also supports Wilt (1974) and Zanon (1974) who felt depth jumping is a plyometric exercise that helps muscles use their strength to generate power for jumping events. The results of this study support Keohane who found a depth jumping program improved jumping both on and off the ice, and do not support Scoles (1978) who reported no vertical jump increases after a depth jumping program was undertaken.

The improvement in jumping ability may be a result of power increases and the possible reasons for these increases should be discussed. Secher, Rorsgaard and Secher (1976) reported that two leg extension strength is approximately 87% of twice the average of one leg extension strength and gave indirect evidence of decreased motor unit activity during two leg extension as compared to one leg extension. It was also indicated that training causes recruitment of more motor units resulting in more force being exerted. Tesch and Karlson (1977) reported that maximum isometric strength (MIS) was linearly correlated at the .001 level with relative distribution of fast twitch (FT) fibres. Thorstensson (1976) found hypertrophy in the FT fibres after an eight week weight training program and found that fast isokinetic contractions of the leg depend on the relative distribution of the FT fibres. He also reported that enzyme activities associated with rapid ATP synthesis increase when fast maximal contractions are repeated five to eight times with brief rest intervals.

In this study the training program was such that FT fibres may have hypertrophied as they are recruited at high muscle tensions and under 'sprint training' repetitions.

If this were so, the MIS should have increased significantly. In this study knee extension strength did not improve but plantar flexion strength did. This may mean that the increase in jump height was due to increases in plantar flexion strength. However the correlation coefficients reveal no significant relationship between vertical jump and plantar flexion strength. Correlations are based on selected ordering so when comparing the two measures the strongest subjects may not necessarily be the best jumpers or the weakest subjects the poorest jumpers. This could result in low correlations. However, an increase in plantar flexion power whatever the initial level may result in improvement of vertical jump. If this is true all subjects could have improved their jumping ability by improving their plantar flexion power and not affected the correlation coefficient because they would keep their relative order.

For all subjects plantar flexion strength improved an average of 38% and sargeant jump improved an average of 10%. Theoretically plantar flexion contributes 22% to the jump (Luhtanen and Komi, 1978). If power gains matched strength gains, increased plantar flexion strength would account for approximately 80% of the vertical jump gains. To the investigators knowledge there have been no studies which correlated MIS changes to fibre contraction speed so it is speculative to state that plantar flexion strength gains explain gains in vertical jump.

Another explanation for the jump improvement could be learning factors in which more motor units are recruited during the jump training. This could also be an explanation for the plantar flexion strength increases. Improved performance because of better coordination of trunk and limb action, is thought to be of little importance in this study as the majority of subjects involved were experienced jumpers prior to the study.

The jumping increases in this study as can be seen in Tables 6 and 8 were significant in trend both linearly and quadraticly. However, observation of the trial means (Table 4) indicates a levelling of the rate of increase. This indicates a quadratic curve which means that continued training would have resulted in decreasing gains. Table 11 shows that the trend for plantar flexion strength was significant both linearly and quadraticly. The level of significance is .05 for the quadratic trend while it is .01 for the linear trend. This would indicate that there were still large strength gains to be made in this program although the curve would have eventually approached an asymptote.

Hypothesis two was not supported wholly because leg extension strength showed no significant gains. Two possible explanations for this are: the nature of the measuring apparatus prevented subjects from exerting maximum force; or that tension developed in the thigh muscles was not enough to cause hypertrophy of the FT fibres (Thorstensson, 1976). The first explanation is not valid as the same cable tensiometer was used for both strength tests and as can be seen from the results the subjects were able to show that there had been an increase in plantar flexion strength. The second explanation is more reasonable as the thigh has a greater cross-sectional area than the calf. A tension high enough to cause hypertrophy of FT fibres in the calf may not be high enough when dispersed in the thigh to cause hypertrophy of FT fibres there. The correlation coefficients of knee extension strength to plantar flexion strength were significant over the tests at the .05 level ($r_{pre} = .62$, $r_{mid} = .39$ and $r_{post} = .49$) which indicates that subjects strong on one test were strong on the other. These correlations would indicate that selected order was maintained in knee extension strength and that lack of significant improvement in knee extension strength was due to lack of training effect rather than error in measurement.

The third hypothesis was not supported as there were no significant differences in the leg strength tests between groups. MIS is directly correlated with relative distribution of FT fibres (Tesch and Karlsson, 1977) and FT fibres hypertrophy when under tension (Thorstensson, 1976). The tensions developed in the three conditions may not have differed enough to cause significant differences in MIS.

The fourth hypothesis was not supported by this study. An explanation for this may be that the training momenta or velocities did not differ enough to cause significant differences in the rates of improvement.

Correlation Coefficients. The correlation coefficients reveal that a strong relationship existed between sargeant jump and standard depth jump. All r values are significant at the .02 level and indicate that good sargeant jumpers were good depth jumpers in terms of height attained ($r_{pre} = .89$, $r_{mid} = .92$, $r_{post} = .91$). When comparing the means of the sargeant jump and standard depth jump (Table 4) it can be seen that the means of the standard depth jumps were approximately .85 of an inch higher than those of the sargeant jumps. The high correlation coefficients indicate that for both jumps each subject was in the same order relative to the other subjects. This means that most subjects jumped higher in the standard depth jump than in the sargeant jump. This supports the results reported by Asmussen and Bonde-Petersen (1974) who found that their subjects jumped higher during the rebound jump of a depth jump than during a sargeant jump.

The only other correlations that were significant were those between knee extension strength and plantar flexion strength and they revealed that subjects who ranked high on one test ranked high on the others.

Summary. Sargeant jump, depth jump and plantar flexion strength improved during the training programs. Knee extension strength did not improve. There were no significant between groups differences on the vertical jump, depth jump and plantar flexion measures.

Results: Force Platform Analysis of the Three Training Conditions.

The following results deal with the analysis of the reaction force characteristics of each of the three types of training depth jumps.

The data recorded from the tracings was obtained by measuring various parameters of these tracings. Figure 2 is a reproduction of a recording and the parameters measured are indicated. The shape of the tracing matches that reported by Asmussen and Bonde-Petersen (1974). The various measures were labelled, for convenience, as follows; landing force, dip force, jump force, total impulse, landing impulse, jump impulse, half jump impulse, total time, landing time, jump time and half jump time. These labels are adapted descriptions of the data.

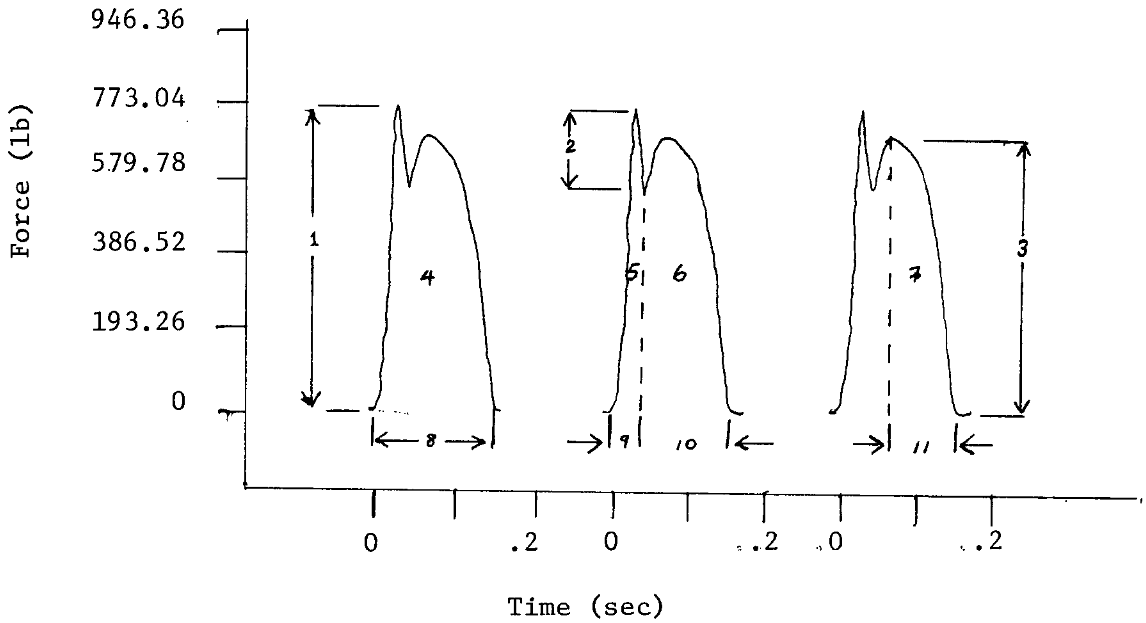
Landing, jump and half jump times are not entirely correct as they were calculated, using as boundaries the dip minimum and jump force maximum.

Table 15 shows the means and standard deviations for each variable measured. Tables 16, 17, 18, 19, 21, 22, 24, 26, 27, 28, 29, display the analyses of variance of each variable when compared over the three types of jumps.

For 2 and 14 deg of freedom critical F at the .05 level is 3.74 and at the .01 level is 6.51 (Ferguson, 1959). As can be seen from the tables there were no significant differences in landing force (F .46, P .639), jump force (F 1.39, P .281), dip force (F .41, P .678), total time (F .689, P .519), landing time (F 1.43, P .272), jump time (F 1.76, P .208), half jump time (F .715, P .506), or landing impulse (F 1.44, P .270) between the three conditions. Total impulse (F 6.88, P .008), jump impulse (F 11.33, P .001), and half jump impulse (F 4.50, P .031) did show significant F values.

Figure 2

FORCE PLATFORM TRACINGS




1. Landing Force (L.F.), (lb)
2. Dip Force (D.F.) (lb)
3. Jump Force (J.F.) (lb)
4. Total Impulse (T.I.) (lb-sec)
5. Landing Impulse (L.I.) (lb-sec)
6. Jump Impulse (J.I.) (lb-sec)
7. Half Jump Impulse (H.J.I.) (lb-sec)
8. Total Time (T.T.) (sec)
9. Landing Time (L.T.) (sec)
10. Jump Time (J.T.) (sec)
11. Half Jump Time (H.J.T.) (sec)

Table 15

Means of Variables

| Variables | | Optimum | Loaded | Between |
|---|---|---|---|---|
| L.F. (lb) | $\bar{X}$ | 789.54 | 770.22 | 784.71 |
| | S.D. | 63.17 | 62.32 | 68.44 |
| J.F. (lb) | $\bar{X}$ | 714.69 | 726.77 | 705.03 |
| | S.D. | 104.79 | 65.25 | 88.22 |
| D.F. (lb) | $\bar{X}$ | 197.99 | 193.16 | 224.55 |
| | S.D. | 112.51 | 123.90 | 85.73 |
| T.I. (lb-sec) | $\bar{X}$ | 170.61 | 187.03 | 169.23 |
| | S.D. | 24.94 | 28.91 | 18.26 |
| L.I. (lb-sec) | $\bar{X}$ | 51.26 | 43.17 | 46.30 |
| | S.D. | 17.79 | 8.88 | 17.09 |
| J.I. (lb-sec) | $\bar{X}$ | 119.35 | 143.86 | 122.75 |
| | S.D. | 25.00 | 25.81 | 23.29 |
| H.J.I. (lb-sec) | $\bar{X}$ | 90.88 | 113.10 | 86.73 |
| | S.D. | 31.60 | 32.38 | 31.17 |
| T.T. (sec) | $\bar{X}$ | .32 | .34 | .32 |
| | S.D. | .07 | .04 | .05 |
| L.T. (sec) | $\bar{X}$ | .08 | .07 | .08 |
| | S.D. | .02 | .01 | .02 |
| J.T. (sec) | $\bar{X}$ | .23 | .27 | .25 |
| | S.D. | .05 | .04 | .06 |
| H.J.T. (sec) | $\bar{X}$ | .18 | .21 | .19 |
| | S.D. | .07 | .06 | .08 |

Table 16

Anova Of Landing Force

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials | 2 | 808.26 | .46 | .639 |
| Error | 14 | 1750.01 | | |

Table 17

Anova Of Jump Force

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials | 2 | 948.50 | 1.39 | .281 |
| Error | 14 | 681.73 | | |

Table 18

Anova of Dip Force

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials | 2 | 2285.22 | .41 | .673 |
| Error | 14 | 5607.55 | | |

Table 19

Anova of Total Impulse

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials | 2 | 784.23 | 6.88 | .008 |
| Error | 14 | 114.03 | | |

Table 20

Newman-Kuels Multiple Comparison Test Of Total Impulse

Table of Q

| | Between | Optimum | Loaded |
|---|---|---|---|
| Between | | .37 | 4.71* |
| Optimum | | | 4.34** |
| Loaded | | | |

* significant at .05 level ($Q_2$= 3.03, $Q_3$= 3.70)

** significant at .01 level ($Q_2$= 4.21, $Q_3$= 4.89)

Table 21

Anova Of Landing Impulse

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials | 2 | 133.09 | 1.44 | .27 |
| Error | 14 | 92.41 | | |

Table 22

Anova Of Jump Impulse

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials | 2 | 1401.20 | 11.23 | .001 |
| Error | 14 | 124.75 | | |

Table 23

Newman-Kuels Multiple Comparisons Test Of Jump Impulse

Table of Q

| | Optimum | Between | Loaded |
|---|---|---|---|
| Optimum | | .09 | 6.21** |
| Between | | | 5.35** |
| Loaded | | | |

* significant at .05 level ($Q_2$= 3.03, $Q_3$= 3.70)

** significant at .01 level ($Q_2$= 4.21, $Q_3$= 4.89)

Table 24

Anova Of Half Jump Impulse

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials | 2 | 1608.26 | 4.50 | .031 |
| Error | 14 | 357.66 | | |

Table 25

Newman-Kuels Multiple Comparison Test Of Half Jump Impulse

Table of Q

| | Between | Optimum | Loaded |
|---|---|---|---|
| Between | | .62 | 3.94* |
| Optimum | | | 3.32* |
| Loaded | | | |

* significant at .05 level ($Q_2$= 3.03, $Q_3$= 3.70)

** significant at .01 level ($Q_2$= 4.21, $Q_3$= 4.89)

Table 26

Anova Of Total Time

| Source | D.F. | Mean Square | F | P |
|---|---|---|---|---|
| Trials | 2 | .0008 | .689 | .519 |
| Error | 14 | .0011 | | |

Table 27

Anova Of Landing Time

| Source | D.F. | Mean Square | F | P |
| --- | --- | --- | --- | --- |
| Trials | 2 | .00032 | 1.430 | .272 |
| Error | 14 | .00022 | | |

Table 28

Anova Of Jump Time

| Source | D.F. | Mean Square | F | P |
| --- | --- | --- | --- | --- |
| Trials | 2 | .0021 | 1.760 | .208 |
| Error | 14 | .0012 | | |

Table 29

Anova of Half Jump Time

| Source | D.F. | Mean Square | F | P |
| --- | --- | --- | --- | --- |
| Trials | 2 | .0011 | .715 | .506 |
| Error | 14 | .0015 | | |

Post-hoc Newman-Kuels multiple comparison tests were administered to the total, jump and half jump impulses to find where the differences existed. Tables 20, 23 and 25 show the Q values for the differences between each pair of means for each variable. For all three variables the impulses of the low velocity, high momentum group were significantly larger than for the two other groups who displayed no significant differences with each other. The critical Q values at the .05 level with 14 deg of freedom are 3.03 for $Q_2$ and 3.70 for $Q_3$. At the .01 level the values are 4.21 for $Q_2$ and 4.89 for $Q_3$.

A multiple comparison of the total impulse variable gives significant differences between the loaded and the unloaded at sub-optimum groups (Q 4.71, P .05) and between the loaded and the unloaded optimum height groups (Q 4.34, P .01). For the jump impulse variable the comparison between the loaded and optimum groups is significant (Q 6.21, P .01), as is the comparison between the loaded and unloaded sub-optimum groups (Q 5.35, P .01).

The half jump impulse comparisons are significant between the loaded and the unloaded sub-optimum groups (Q 3.94, P .05) and between the loaded and the optimum groups (Q 3.32, P .05).

Discussion

Landing forces, dip forces, landing times and landing impulses were not significantly different because the landing phases of the jumps overlapped the take-off phases. The landing impulses could not be measured because the subjects began to apply forces to decelerate the body in preparation for take-off before the landing sequence was completed. This overlap also resulted in inaccurate measuring of landing times. The fact that landing forces were not significantly different indicates that differences in landing impulses could not be measured or determined. If true measures of landing impulses were taken the overload and optimum height groups would have had the same impulse values because they landed with the same momenta and the unloaded at sub-optimum height group would have had a smaller impulse value because they landed with less momentum than the other groups (momentum is equal to impulse, mass x velocity = force x time).

Jump force maximums were not significantly different and may be indicative of a maximum contraction force value in all three jumps. That is, the subjects may have been capable only of applying a certain maximum force and they applied it in each of the depth jump conditions, which resulted in peak reaction forces in the three conditions being equal. Again the overlap of the landing and take-off phases adversly affected the measurement of these forces.

Total time on the ground during the jump averaged .325 sec for all conditions. Jump time and half jump time averaged .25 sec and .19 sec respectively. But the landing and take-off phase overlap resulted in the inability to measure these times accurately. There were no significant between groups differences for any of the measures.

Three of the four impulse measures showed significant differences between the conditions. From Tables 20, 23 25 it can be seen that the loaded impulses were significantly different from the two other conditions which in turn were not significantly different. However, the jump impulses and half jump impulses were hidden in the total impulses because of the overlap between the landing and take-off phases. As a result the only true measure for comparison of the training condition jumps are the total impulses. Total impulse is a measure of landing and take-off impulses and since the total impulses of the loaded group were greater than the total impulses of the optimum height group and since their landing impulses were equal (because the landing momenta were equal and momentum = impulse), then the loaded group developed greater impulses for take-off. The unloaded at sub-optimum height group and the optimum height group showed no significant differences in the impulse measures and this may be an indication that the landing momenta (and therefore impulses) were not different enough to be measured. The similar total impulses indicate that the take-off impulses developed were similar for both conditions.

Summary. The force tracings agreed with those reported by Asmussen and Bonde-Petersen (1974) and data obtained from them showed no significant differences between the three jump conditions in landing force, dip force, jump force, total time, landing time, jump time, half jump time, or landing impulse. Significant differences were found between the two unloaded groups when compared to the loaded group on the impulse measures and these differences indicate that a higher average force was developed for take-off in loaded depth jumping.

# Chapter 5

## SUMMARY AND CONCLUSIONS

Leg power would seem to be an extremely important requirement in jumping and most athletic activities. Any method which may improve leg power becomes important in training activities designed to improve performance in athletics. Plyometric drills have been credited with improving power, more specifically depth jumping has been said to improve leg power.

Depth jump training is an activity where the athlete jumps down from a height and jumps again as quickly as possible after contacting the landing surface. The benefits of this program come from improvement of the reactive ability of the muscles of the legs.

The purpose of this investigation was to study the comparative effects on vertical jump of three different depth jumping programs. The characteristics of data obtained from the force place from landing to take-off during performance of each of the depth jumping conditions were also analyzed.

Thirty-eight male University of British Columbia student athletes volunteered to take part in this study. This number was reduced to 28 due to injuries and withdrawal from the study. All subjects were members of University teams and competed at the varsity or junior varsity level.

The subjects from any one team that would be included in any one group were chosen randomly from that team.

Subjects were pre, mid and posttested on the Sargeant Jump Test, Standard Depth Jump Test, Knee Extension Strength Test and Plantar Flexion Strength Test. After the study eight volunteers were tested on the Kistler force platform performing the three training depth jump conditions and the results were recorded.

This study was a 3 x 3 factorial design with repeated measures in the second factor. The independent variables were the treatment factor with three levels and the time factor with three levels. Four dependent variables were measured: sargeant jump height, standard depth jump height, knee extension strength and plantar flexion strength.

All groups participated in a six week depth jumping program that was comprised of one depth jumping exercise performed at different heights for each group and a different loading for one group.

Results of the analysis of variances showed that all three training groups inproved in jumping ability and plantar flexion strength with no differences between groups in rate of improvement and that no groups improved in knee extension strength. Highly significant correlations were found between sargeant jump and depth jump ability and significant correlations were found between knee extension and plantar flexion strength.

The analysis of variance of data obtained from the force platform showed no significant difference in characteristics between the three jumping conditions, except in impulse. The loaded condition showed a significantly higher impulse than the other two conditions.

## CONCLUSIONS

The following conclusions seem valid based on the findings of this study.

1. A six week depth jump training program is effective in improving vertical jump as measured by the Sargeant and Standard Depth Jump Tests.

2. A six week depth jump training program is effective in improving plantar flexion strength as measured by the Plantar Flexion Strength Test.

3. Loading during a six week depth jump training program does not adversely affect gains in vertical jump when compared to programs of un-

loaded depth jump training performed with landing momentum similar to that of the loaded program.

4. Jumping from a sub-optimum height in a six week depth jump training program does not adversely affect gains in vertical jump when compared to the results of a depth jump training program performed from optimum height.

5. An unloaded six week depth jump training program does not adversely affect strength gains when compared to the results of a loaded depth jump training program.

6. Vertical jumping ability as measured by the Sargeant Jump Test is highly correlated with depth jumping as measured by the Standard Depth Jump Test.

7. Knee extension strength as measured by the Knee Extension Test is significantly correlated with plantar flexion strength as measured by the Plantar Flexion Test.

8. Loaded depth jumps produce significantly greater impulses than those produced by unloaded depth jumps when landing momenta are similar for both types of depth jumps.

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# APPENDICES

Appendix A: Individual Data

Pretest Data Optimum Group

| Subject # | Sargeant Jump (in) | Depth Jump (in) | Knee Extension (lb) | Plantar Flexion (lb) |
|---|---|---|---|---|
| 1 | 26 | 28 | 176 | 260 |
| 2 | 20 | 23 | 320 | 300 |
| 3 | 19 | 22 | 220 | 247 |
| 4 | 28 | 28 | 253 | 210 |
| 5 | 24 | 25 | 220 | 320 |
| 6 | 25 | 26 | 210 | 300 |
| 7 | 22 | 22 | 247 | 270 |
| 9 | 23 | 23 | 176 | 260 |
| 10 | 20 | 21 | 160 | 180 |
| $\bar{X}$ | 22.80 | 24.00 | 219.50 | 257.40 |
| S.D. | 2.94 | 2.58 | 46.47 | 43.45 |

Pretest Data Overload Group

| Subject # | Sargeant Jump (in) | Depth Jump (in) | Knee Extension Strength (lb) | Plantar Flexion (lb) |
|---|---|---|---|---|
| 11 | 22 | 23 | 193 | 215 |
| 12 | 23 | 23 | 227 | 287 |
| 13 | 22 | 22 | 220 | 193 |
| 14 | 24 | 24 | 220 | 227 |
| 15 | 19 | 22 | 227 | 215 |
| 16 | 25 | 25 | 300 | 333 |
| 17 | 17 | 17 | 267 | 320 |
| 18 | 20 | 21 | 233 | 233 |
| 19 | 23 | 23 | 270 | 275 |
| 20 | 22 | 24 | 176 | 144 |
| $\bar{X}$ | 21.70 | 22.40 | 233.30 | 244.20 |
| S.D. | 2.41 | 2.22 | 36.93 | 58.88 |

Pretest Data

Unloaded Sub-Optimum Group

| Subject # | Sargeant Jump (in) | Depth Jump (in) | Knee Extension Strength (lb) | Plantar Flexion (lb) |
|---|---|---|---|---|
| 21 | 28 | 30 | 265 | 293 |
| 22 | 24 | 22 | 175 | 172 |
| 23 | 24 | 24 | 287 | 287 |
| 24 | 21 | 24 | 280 | 227 |
| 25 | 23 | 24 | 227 | 233 |
| 26 | 21 | 21 | 293 | 320 |
| 27 | 22 | 22 | 247 | 215 |
| 28 | 23 | 24 | 233 | 265 |
| $\bar{X}$ | 23.25 | 23.88 | 250.88 | 251.50 |
| S.D. | 2.25 | 2.75 | 39.26 | 48.48 |

Midtest Data

Optimum Group

| Subject # | Sargeant Jump (in) | Standard Depth (in) | Knee Extension Strength (lb) | Plantar Flexion Strength (lb) |
|---|---|---|---|---|
| 1 | 28 | 30 | 193 | 320 |
| 2 | 23 | 27 | 267 | 287 |
| 3 | 21 | 22 | 213 | 300 |
| 4 | 31 | 31 | 240 | 287 |
| 5 | 28 | 28 | 213 | 327 |
| 6 | 27 | 27 | 220 | 340 |
| 7 | 24 | 23 | 280 | 333 |
| 8 | 24 | 25 | 205 | 393 |
| 9 | 22 | 22 | 193 | 260 |
| 10 | 20 | 21 | 156 | 280 |
| $\bar{X}$ | 24.80 | 25.60 | 218.00 | 36.58 |
| S.D. | 3.55 | 3.53 | 36.58 | 36.29 |

Midtest Data

Overload Group

| Subject # | Sargeant Jump (in) | Standard Depth (in) | Knee Extension Strength (lb) | Plantar Flexion Strength (lb) |
|---|---|---|---|---|
| 11 | 24 | 24 | 213 | 280 |
| 12 | 23 | 23 | 260 | 287 |
| 13 | 24 | 25 | 240 | 267 |
| 14 | 27 | 28 | 240 | 287 |
| 15 | 22 | 24 | 233 | 300 |
| 16 | 28 | 29 | 300 | 373 |
| 17 | 19 | 20 | 227 | 320 |
| 18 | 24 | 25 | 233 | 300 |
| 19 | 25 | 25 | 233 | 373 |
| 20 | 24 | 25 | 205 | 270 |
| $\bar{X}$ | 24.00 | 24.80 | 238.40 | 305.70 |
| S.D. | 2.49 | 2.49 | 26.34 | 38.67 |

Midtest Data

Unloaded Sub-Optimum Group

| Subject # | Sargeant Jump (in) | Standard Depth Jump (in) | Knee Extension (lb) | Plantar Flexion Strength (lb) |
|---|---|---|---|---|
| 21 | 28 | 01 | 260 | 370 |
| 22 | 26 | 25 | 275 | 280 |
| 23 | 26 | 25 | 270 | 270 |
| 24 | 22 | 24 | 310 | 360 |
| 25 | 23 | 23 | 200 | 293 |
| 26 | 23 | 23 | 300 | 370 |
| 27 | 23 | 24 | 300 | 360 |
| 28 | 25 | 27 | 233 | 265 |
| $\bar{X}$ | 24.50 | 25.25 | 68.50 | 321.00 |
| S.D. | 2.07 | 2.66 | 37.37 | 47.88 |

Posttest Data

Optimum Group

| Subject # | Sargeant Jump (in) | Depth Jump (in) | Knee Extension (lb) | Plantar Flexion (lb) |
|---|---|---|---|---|
| 1 | 28 | 30 | 187 | 333 |
| 2 | 24 | 27 | 320 | 320 |
| 3 | 21 | 22 | 205 | 333 |
| 4 | 33 | 33 | 227 | 327 |
| 5 | 28 | 29 | 205 | 327 |
| 6 | 27 | 29 | 220 | 350 |
| 7 | 25 | 23 | 267 | 400 |
| 8 | 25 | 25 | 227 | 393 |
| 9 | 22 | 23 | 187 | 260 |
| 10 | 21 | 21 | 160 | 273 |
| $\bar{X}$ | 25.40 | 26.20 | 220.50 | 331.60 |
| S.D. | 3.75 | 3.99 | 45.38 | 44.13 |

Posttest Data

Loaded Group

| Subject # | Sargeant Jump (in) | Depth Jump (in) | Knee Extension (lb) | Plantar Flexion (lb) |
|---|---|---|---|---|
| 11 | 24 | 24 | 220 | 280 |
| 12 | 23 | 23 | 287 | 393 |
| 13 | 24 | 25 | 240 | 275 |
| 14 | 27 | 28 | 210 | 300 |
| 15 | 23 | 25 | 227 | 327 |
| 16 | 27 | 29 | 333 | 400 |
| 17 | 20 | 21 | 253 | 400 |
| 18 | 25 | 24 | 220 | 327 |
| 19 | 26 | 26 | 267 | 470 |
| 20 | 25 | 26 | 205 | 275 |
| $\bar{X}$ | 24.40 | 25.10 | 246.20 | 344.70 |
| S.D. | 2.12 | 2.33 | 40.09 | 67.23 |

Posttest Data

Unloaded Sub-Optimum Group

| Subject # | Sargeant Jump (in) | Depth Jump (in) | Knee Extension (lb) | Plantar Flexion (lb) |
|---|---|---|---|---|
| 21 | 28 | 32 | 233 | 370 |
| 22 | 25 | 26 | 300 | 300 |
| 23 | 27 | 26 | 270 | 275 |
| 24 | 24 | 25 | 253 | 370 |
| 25 | 23 | 24 | 210 | 320 |
| 26 | 24 | 24 | 300 | 470 |
| 27 | 23 | 25 | 253 | 400 |
| 28 | 24 | 26 | 233 | 400 |
| $\bar{X}$ | 24.75 | 26.00 | 256.50 | 363.13 |
| S.D. | 1.83 | 2.56 | 32.20 | 63.07 |

Landing Force Data (lb)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | 811.27 | 849.9 | 811.27 |
| 2 | 811.27 | 811.27 | 811.27 |
| 3 | 772.64 | 676.06 | 811.27 |
| 4 | 753.32 | 811.27 | 811.27 |
| 5 | 656.74 | 695.38 | 618.11 |
| 6 | 811.27 | 772.64 | 791.96 |
| 7 | 849.90 | 734.01 | 830.59 |
| 8 | 849.90 | 811.27 | 791.96 |
| $\bar{X}$ | 789.54 | 770.22 | 784.71 |
| S.D. | 63.17 | 62.32 | 68.44 |

Jump Force Data (lb)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | 753.32 | 753.32 | 753.32 |
| 2 | 791.96 | 791.96 | 772.64 |
| 3 | 714.69 | 695.38 | 714.69 |
| 4 | 598.80 | 676.06 | 637.43 |
| 5 | 521.53 | 618.11 | 521.53 |
| 6 | 714.69 | 695.38 | 695.38 |
| 7 | 811.27 | 695.38 | 656.74 |
| 8 | 811.27 | 791.96 | 772.64 |
| $\bar{X}$ | 714.69 | 726.77 | 705.03 |
| S.D. | 104.79 | 65.25 | 88.22 |

Dip Force Data (lb)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | 154.53 | 367.00 | 212.48 |
| 2 | 19.32 | 19.32 | 38.63 |
| 3 | 115.90 | 0.0 | 289.74 |
| 4 | 193.16 | 231.79 | 193.16 |
| 5 | 309.06 | 212.48 | 270.42 |
| 6 | 193.16 | 212.48 | 270.42 |
| 7 | 386.32 | 270.42 | 309.06 |
| 8 | 212.48 | 231.79 | 212.48 |
| $\bar{X}$ | 197.99 | 193.16 | 224.55 |
| S.D. | 112.51 | 123.90 | 85.73 |

Total Impulse Data (lb-sec)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | 194.32 | 198.19 | 180.99 |
| 2 | 168.82 | 166.89 | 156.85 |
| 3 | 185.43 | 210.74 | 193.16 |
| 4 | 209.96 | 220.98 | 194.51 |
| 5 | 132.12 | 141.39 | 148.35 |
| 6 | 151.44 | 159.36 | 150.47 |
| 7 | 161.10 | 214.41 | 166.12 |
| 8 | 161.67 | 184.27 | 163.41 |
| $\bar{X}$ | 170.61 | 187.03 | 169.23 |
| S.D. | 24.94 | 28.91 | 18.26 |

Landing Impulse Data (lb-sec)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | 62.97 | 33.99 | 46.55 |
| 2 | 87.69 | 54.08 | 79.59 |
| 3 | 46.55 | 44.62 | 34.00 |
| 4 | 48.86 | 48.30 | 58.24 |
| 5 | 28.59 | 30.13 | 25.50 |
| 6 | 51.00 | 40.76 | 32.64 |
| 7 | 37.48 | 54.47 | 50.22 |
| 8 | 46.93 | 39.01 | 43.65 |
| $\bar{X}$ | 51.26 | 43.17 | 46.30 |
| S.D. | 17.79 | 8.88 | 17.09 |

Jump Impulse Data (lb-sec)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | 131.35 | 164.19 | 134.44 |
| 2 | 81.13 | 112.81 | 77.26 |
| 3 | 138.88 | 166.12 | 159.16 |
| 4 | 161.10 | 172.68 | 126.27 |
| 5 | 103.53 | 111.26 | 122.85 |
| 6 | 100.44 | 118.60 | 117.83 |
| 7 | 123.62 | 159.94 | 115.90 |
| 8 | 114.74 | 145.26 | 119.76 |
| $\bar{X}$ | 119.35 | 143.86 | 122.95 |
| S.D. | 25.00 | 25.81 | 23.29 |

Half Jump Impulse Data (lb-sec)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | 83.06 | 139.08 | 65.67 |
| 2 | 38.63 | 53.70 | 45.97 |
| 3 | 119.76 | 127.49 | 135.21 |
| 4 | 146.42 | 154.53 | 111.26 |
| 5 | 91.94 | 93.88 | 106.24 |
| 6 | 76.49 | 91.17 | 86.92 |
| 7 | 83.06 | 132.12 | 50.22 |
| 8 | 87.69 | 112.81 | 92.33 |
| $\bar{X}$ | 90.88 | 113.10 | 86.73 |
| S.D. | 31.60 | 32.38 | 31.17 |

Total Time Data (sec)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | .34 | .34 | .32 |
| 2 | .22 | .28 | .26 |
| 3 | .34 | .38 | .38 |
| 4 | .44 | .40 | .34 |
| 5 | .34 | .30 | .40 |
| 6 | .28 | .30 | .30 |
| 7 | .28 | .36 | .30 |
| 8 | .28 | .32 | .30 |
| $\bar{X}$ | .32 | .34 | .32 |
| S.D. | .07 | .04 | .05 |

Landing Time Data (sec)

| Subject | Optimum | Loading | Between |
|---|---|---|---|
| 1 | .10 | .06 | .08 |
| 2 | .06 | .08 | .10 |
| 3 | .10 | .08 | .06 |
| 4 | .10 | .08 | .08 |
| 5 | .08 | .06 | .06 |
| 6 | .08 | .06 | .06 |
| 7 | .06 | .06 | .08 |
| 8 | .08 | .08 | .10 |
| $\bar{X}$ | .08 | .07 | .08 |
| S.D. | .02 | .01 | .02 |

Jump Time Data (sec)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | .24 | .28 | .24 |
| 2 | .16 | .20 | .16 |
| 3 | .24 | .30 | .32 |
| 4 | .34 | .32 | .26 |
| 5 | .26 | .24 | .34 |
| 6 | .20 | .24 | .24 |
| 7 | .22 | .30 | .22 |
| 8 | .20 | .24 | .20 |
| $\bar{X}$ | .23 | .27 | .25 |
| S.D. | .05 | .04 | .06 |

Half Jump Time Data (sec)

| Subject | Optimum | Loaded | Between |
|---|---|---|---|
| 1 | .16 | .20 | .12 |
| 2 | .08 | .10 | .10 |
| 3 | .20 | .24 | .28 |
| 4 | .30 | .30 | .24 |
| 5 | .24 | .20 | .30 |
| 6 | .16 | .18 | .20 |
| 7 | .16 | .24 | .12 |
| 8 | .16 | .18 | .16 |
| $\bar{X}$ | .18 | .21 | .19 |
| S.D. | .07 | .06 | .08 |

## Appendix B: Sample Calculations and Tables

A. Calculation of Velocities Attained from Heights in the Training Range.

s = height from floor, t = time, v = velocity,

a = gravity, $s = \frac{1}{2} at^2$, $v = at$,

therefore $t = (\frac{2s}{a})^{\frac{1}{2}}$

and $v = a(\frac{2s}{a})^{\frac{1}{2}}$

set $H_1$ = 24" $\qquad a = 384 \text{ in/sec}^2$

then $V_1 = 384 \ (\frac{48}{384})^{\frac{1}{2}} = 384\ (.35355) = 135.76$ in/sec

velocity in feet/sec is: $\frac{135.76}{12} = 11.31$ ft/sec

B. Calculation of Training Heights

$H_1$ = optimum height, $H_2$ = loaded height and

$H_3$ = height between for unloaded sub-optimum group

mo = momentum, m = mass, v = velocity,

$$mo = mv$$

if $mo_1 = mo_2$ then $m_1 v_1 = m_2 v_2$

however in the loaded condition $m_2 = m_1 + .15\ m_1$

so $m_1 v_1 = (m_1 + .15 m_1)\ v_2 \qquad v_2 = \frac{m_1 v_1}{1.15 m_1}$

$v_2 = \frac{v_1}{1.15}$

set $H_1$ = 24" then $V_1$ = 11.31 ft/sec

$V_2 = \frac{11.31}{1.15} = 9.83$ ft/sec

from table 1 the training height with a

velocity closest to 9.83 ft/sec is 18 in so

$H_2$ = 18"

$H_3$ is the height closest to the average at $H_1$ and $H_2$

$$H_3 = \frac{H_1 + H_2}{2} = \frac{4 + 18}{2} = 21''$$

If $H_3$ not an even inch then the height closest to and below is taken as $H_3$

C. Calculation of Force Plate Values from the Raw Data

force taken on the vertical axis

time on the horizontal axis

1 cm vertically = 193.16 lb

1 cm horizontally = .2 sec

1 sq cm = 38.632 lb-secs

if height of landing trace = 4.2 cm

landing force = 4.2 (193.16) = 811.27 lb

if trace is 1.7 cm beginning to end on the horizontal axis then:

total time = 1.7 (.2) = .34 sec

if the area under the curve is 5.03 sq cm then,

impulse = 5.03 (38.632) = 194.32 lb-secs

Jumping force and dip force were calculated in the same manner as the landing force.

Jump time and half jump time were measured in the same manner as total time. The distance used in the case of jump time was from that point where a vertical line from the minimum dip value intersected the horizontal axis, to the end of the tracing. The distance of the half jump time was taken from a point on the horizontal directly below the peak jump force to the end of the tracing.

Jump impulse was calculated in the same was as total impulse but the area used was that bounded by the tracing, the horizontal axis and the line perpendicular to the horizontal axis passing through the dip minimum. Half jump impulse was calculated from the area bound by tracing the horizontal axis and the line perpendicular to the horizontal axis passing through the jump force maximum.