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Title: Comparative Cinematographic Analysis of Depth Jumping and Long Jump Take-off as Performed by Male College Long Jumpers.

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Six male college long jumpers volunteered as subjects to determine the kinematic differences between depth jumps from 0.75 m and 1.10 m, and long jump take-off. The variables examined were approach and take-off vertical, horizontal and resultant velocities with contact time and angles of take-off.

Subjects undertook six depth jump practice sessions, over a four week period prior to filming. Film speed was 200 frames per second. One trial was filmed of each subject for each condition. Film was analysed on a digitizer interfaced with a microcomputer.

Analysis of variance revealed no significant differences among all three conditions for take-off vertical velocities and contact time ($p<.01$). Differences existed between long jump take-off and both depth jumps for all other variables.

Comparative Cinematographic Analysis of Depth Jumping and Long Jump Take-off as Performed by Male College Long Jumpers

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Typed by Douglas M. Hicks

Dedicated to my wife Carol whose support
is far in excess of what could be expected
in any relationship.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

COMPARATIVE CINEMATOGRAPHIC ANALYSIS OF DEPTH JUMPING AND LONG JUMP TAKE-OFF AS PERFORMED BY MALE COLLEGE LONG JUMPERS

CHAPTER I

INTRODUCTION

Improvement in athletic performance is a goal of athletes, coaches and physical educators. Contemporary athletes are breaking the records of their predecessors. Coaches and physical educators are continually searching for training procedures which will assist athletes in enhancing athletic performance. One procedure which may enhance performance is plyometrics. The roots of the word may have been tied to the Greek origins "plio" meaning more and "metric" meaning to measure (Chu, 1983). The term now relates to specific exercises which cause rapid stretching of muscle tissue while the muscle(s) are undergoing eccentric contraction. The purpose is to develop a forceful movement over a short period of time (Chu, 1983).

There are basically two forms of plyometrics. The first is depth jumping which consists of jumping from a predetermined height, landing on either one or both feet and rebounding from the landing surface with a dynamic vertical thrust. This rebounding may vary in its vertical and horizontal components of motion depending upon the requirements of the training procedure. The second is bounding, which is performed on the ground in both single, double or alternating leg movement patterns (Chu,1983).

Following contact with the landing surface, in the performance of a depth jump, the acceleration of the body towards the landing surface is stopped by forceful eccentric contraction of the leg muscles. This phase of the depth jump is referred to as the negative work phase. The eccentric contraction stores energy in these muscles, the energy being referred to as stored elastic energy. The storing of this energy is then immediately followed by an equal and opposite reaction, utilizing the natural elastic tendencies of the muscles to produce a kinetic energy system (Chu 1983). Chu (1983) goes on to explain that the athlete experiences a neuro-muscular reaction to the ground contact as a result of depth jumping and also a reaction in accordance with the amount of elastic strength that the athlete possesses.

Chu (1984) identifies the muscle mechanism involved in depth jumping as the spindle receptors. They are sensory in nature and are sensitive, not only to the amount of stretching they undergo, but also the rate of stretching. This sensory information is transmitted to the spinal cord through the synaptic junction to the motor horn cells that supply information to the extrafusal fibers. The rest is a protective reaction of the extrafusal fibers to reverse the lengthening process and to rapidly shorten the muscle by concentric contraction. Plyometrics and therefore depth jumps, are used to prepare the neuro-muscular system involved, to react with maximum speed to the lengthening of the muscle and in turn develop the ability of the muscle to shorten with maximum force.

There will be a number of studies referred to later that deal with the effects of depth jumping on strength development, vertical jump, sprinting, and standing long jump. Verhoshanski (1967) refers to the principle of dynamic conformity. This principle suggests that specialized strength preparation should be chosen so that it has maximum conformity with the basic physiological requirements of the sport. These requirements should relate to strength required, time of execution, maximum speed developed, the regimen of work of the muscles, and finally, the amplitude of the work movement. He goes on to say that depth jumps have proved useful to jumpers in terms of this principle.

This study was designed to determine the kinematic relationship between take-off in long jump and the two heights of depth jump proposed by Verhoshanski (1967) - 0.75 and 1.10 meters. The variables examined were, approach vertical velocity, approach horizontal velocity, approach resultant velocity, take-off vertical velocity, take-off horizontal velocity, take-off resultant velocity, contact time, angle of take-off. Winter (1979) describes kinematic variables as involved in the description of the movement, independent of the forces that cause the movement. An assessment of a running broad (long) jump, for example, may require only the velocity, angle, and height of the body's center of gravity at takeoff (Winter,1979).

Statement of Problem

The proposed problem was to assess the kinematic relationship between take-off in long jump and performance of depth jumps from 0.75 and 1.10 meters, in terms of approach and take-off velocities, contact times and angles of take-off.

The study is concerned with eight major areas:

1. The relationship between approach vertical velocities developed during the depth jump from 0.75 m, 1.10 m and long jump take-off.

2. The relationship between approach horizontal velocities developed during the depth jump from 0.75 m, 1.10 m and long jump take-off.

3. The relationship between approach resultant velocities developed during the depth jump from 0.75 m, 1.10 m and long jump take-off.

4. The relationship between take-off vertical velocities developed during the depth jump from 0.75 m, 1.10 m and long jump take-off.

5. The relationship between take-off horizontal velocities developed during the depth jump from 0.75 m, 1.10 m and long jump take-off.

6. The relationship between take-off resultant velocities developed during the depth jump from 0.75 m, 1.10 m and long jump take-off.

7. The relationship between contact time with the take-off board during the depth jump from 0.75 m, 1.10 m and the long jump take-off.

8. The relationship between the angle of take-off during the depth jump from 0.75 m, 1.10 m and long jump take-off.

Significance of Study

The effects of plyometric training as determined by vertical jump, lifting weights, isokinetic devices and running short sprints, have been examined in a number of studies. Improvement or lack of improvement provided the basis for determining whether or not plyometric training was likely to influence athletic development. The kinetic and kinematic variables in long jump technique have also been studied on a number of occasions. These studies have provided quantitative data about the appropriateness of particular techniques related to performance of the long jump.

The purpose of this study was to collect kinematic data in relation to long jump take-off and depth jumps from two heights, 0.75 and 1.10 meters. Verkhoshanski (1969) suggests that in the construction of a system of strength training it is necessary to correlate training methods with the requirements of the skill during performance. Winter (1979) refers to "input discovery" as using technique analysis for the collection of kinematic data. Input discovery of this nature is extremely valuable, and the results of this study should contribute to a base level of information for future decision making, in regard to the appropriateness of depth jumping as a training technique for long jump take-off.

Methodology

Six male long jumpers from the Oregon State University Track and Field Team volunteered to be subjects in this study. The take-off of a long jump performance was filmed for each subject. Depth jumps from two heights were also filmed as performed by each subject. The camera was positioned to the side and at right angles to the point of contact with the take-off board.

The take-off leg of each subject was identified. Subjects were filmed performing the depth jumping and long jump take-off with their take-off leg closest to the camera. Each subject was filmed one after the other in a set order. This order was followed while filming depth jumps from 0.75 meters firstly, followed by depth jumps from 1.10 meters and then the long jump take-off.

A Redlake Locam high speed camera was used for filming, which was fitted with an Angenieux 12:1 200mm lens. The maximum "F Stop" was 2.2. The film used was Kodak 7277 4X reversal. The digitizing unit was a Calcomp 9100 Graphics Digitizer interfaced with an IBM XT Personal Computer. The film speed was 200 frames per second.

Delimitations and Limitations

Factors of internal validity can produce changes which might be mistaken for the results of treatment (Winter, 1979). In the case of this study it was the intention of the investigator to cause a situation where the subjects would perform at their best as a result of high voluntary motivation. For a valid comparison to be made between long jump take-off and depth jump procedures subjects should perform as near to their best as possible. For this reason data were collected in the week following the Pacific 10 Conference Track and Field Championships, which was when these subjects were at peak performance level. The subjects used their regular competition spiked jump shoes in long jump and the nonspiked running shoes for the depth jumps. These were the shoes regularly worn for these respective skills. Subjects were instructed to jump as they would for a regular competition. Even though subjects had experience in various types of plyometric exercises, prior to filming, they were instructed in the required technique for depth jumps.

Standards of performance were set in terms of long jump and depth jump. If these standards were not met the performance was rejected. Subjects were required to jump no less than 90% of the distance of their best jump for the Spring season 1985. For the depth jump procedure, subjects were required to land on the long jump take-off board, take-off and land again no nearer the depth jump platform than they did on the original landing.

A benefit of using college level athletes as opposed to regular college students was that the results could be generalized to the population that the subjects represent. The limiting factor though was the availability of such subjects. The internal validity increases with larger subject populations and therefore the results of the study can be generalized to population that the subjects represent with greater certainty. Coaches, though, are generally reluctant to release athletes into a situation where they (the coaches) are not in total control. These factors must be considered in interpreting these data.

Definition of Terms

Approach Velocity for Long Jump

The velocity which resulted from the approach run prior to contact with the take-off board.

Approach Velocity for Depth Jumping

The approach velocity reached after stepping from the boxes and prior to landing on the long jump take-off board.

Take-off Velocity for Long Jump

The resultant of the vertical and horizontal components of velocity from the take-off.

Take-off Velocity for Depth Jumping

The resultant of the vertical and horizontal components of velocity from the take-off.

Contact Time for Long Jump

The time from when the take-off foot of the subject initially touched the take-off board to when that same foot left the take-off board.

Contact Time for Depth Jumping

The time from when the first foot made contact with the take-off board to when the last remaining foot left the take-off board.

Angles of take-off

The angle made with the landing surface and the subjects' center of mass, at the point of take-off where the take-off foot leaves the landing surface.

Hypotheses

Table 1. Hypotheses Tested.

Ho 1-8: No significant relationship exists between.

Ho	Variable	and	Variable	and	Variable
1	Approach vertical velocities				
	Depth jump 0.75 m		Depth jump 1.10 m		Long jump take-off
2	Approach horizontal velocities				
	Depth jump 0.75 m		Depth jump 1.10 m		Long jump take-off
3	Approach resultant velocities				
	Depth jump 0.75 m		Depth jump 1.10 m		Long jump take-off
4	Take-off vertical velocities				
	Depth jump 0.75 m		Depth jump 1.10 m		Long jump take-off
5	Take-off horizontal velocities				
	Depth jump 0.75 m		Depth jump 1.10 m		Long jump take-off
6	Take-off resultant velocities				
	Depth jump 0.75 m		Depth jump 1.10 m		Long jump take-off
7	Contact time				
	Depth jump 0.75 m		Depth jump 1.10 m		Long jump take-off
8	Angle of take-off				
	Depth jump 0.75 m		Depth jump 1.10 m		Long jump take-off

CHAPTER II

REVIEW OF LITERATURE

Introduction

Cause and effect are ever present considerations in the minds of coaches, physical educators and athletes in the desire to increase levels of athletic performance. This review refers to a number of studies that have attempted to determine the effects of depth jump training on athletic performance.

A number of studies have been conducted to determine the kinematic factors related to long jump. There is, however, little literature dealing with the relationship of kinematic factors of long jump and that of the depth jump as conducted from two different heights. This review will attempt to highlight kinematic factors with regard to the take-off in long jump and studies conducted dealing with depth jumping as a training procedure.

Verkhoshanski (1969) reports that effectiveness in the take-off in the long jump is tied to the execution of greatest force during the shortest time to achieve best results. The ability of the muscles to change performance during the phase of amortization (leg flexion in beginning of take-off) is the key to accelerating the body from the take-off board. The "reactive ability" of the muscles must be increased to reduce the period in contact with the take-off board. The ideal would therefore be to have training procedures that relate directly to the phase of amortization in the jump. Verkhoshanski (1969) suggests that depth jumping from predetermined heights can artificially create the required conditions.

Plyometric Exercise

A number of studies have been conducted in the area of plyometric exercise with most directing attention to the development of muscle power, strength or vertical jumping ability. Studies tend not to be related to particular athletic skills within a subject population, rather, the tendency is to show a training effect on a particular population, whether it be football players, volleyball players or college students.

A plyometric exercise is an exercise in which the athlete utilizes the force of gravity to store energy within the muscular framework of the body. The storing of energy is then immediately followed by an equal and opposite reaction, utilizing the natural elastic tendencies of the muscles to produce a kinetic energy system (Chu, 1984). The rapid stretching of the muscle-tendon tissue, during the eccentric (negative work) phase of the depth jump landing, increases the internal muscular tension resulting in forceful shortening of the muscle. Cavagna

(1977) reports that stored elastic energy is greater resulting from a predetermined fall than for muscle shortening after isometric contraction. During the fall, the contracting muscle stretches causing tension to the series elastic fibers of the muscle. The forces at the extremities of the muscle result in activating the series elastic elements (myotatic reflex). The result is a greater force of muscle contraction.

Depth Jumping

Clutch, Wilton, McGown and Byrne (1983) studied the effects of depth jumping and weight training on leg strength and vertical jump. Twelve male volunteers enrolled in a weight training class were randomly assigned to three groups. The treatments were: (a) maximum vertical jump, (b) 0.3 m depth jumps with no rebound, and (c) 0.75 m and 1.10 m depth jumps. Each treatment was four weeks in duration and was combined with a one-half squat training routine onto an adjustable bench to ensure a constant squat depth. Following this treatment two subjects were assigned to each group and experienced the treatment in -one of six different orders. Each group was tested strength using the following protocol: strength using 1RM squat, vertical jump, cable tension test for maximum knee isometric contraction and pressure platform, measuring differences between take-off and landing forces.

All groups made gains on all test results, however there was no significant difference between groups on any of the test results.

These same authors conducted another study using 16 members from a weight training class and 16 members from the men's volleyball team at Brigham Young University-Hawaii. Subjects were divided into two experimental groups. One group was subjected to depth jumps at 0.75 m and 1.10 m with a weight lifting program which involved dead lift, bench press, and parallel squat. The other group was subjected to a weight lifting program, the same as the first group. A pre-test and post-test was conducted using a vertical jump procedure. The results showed that the treatment of performing with depth jumps was not more effective than the treatment of performing without depth jumps. All groups showed significant gains in vertical jump, however the volleyball team gained more than the weight training class. Groups performing depth jumps showed no significant improvement in performance over groups not performing depth jumps. The group of weight lifters exposed to depth jumping showed gains in vertical jump. The conclusion drawn was that depth jumps added nothing extra to a program that already includes weight training and a variety of jumps. The volleyball players continued normal training of 2.5 hours per day, five days a week. The discussion of results would have been enhanced had the training regimen for the volleyball players been reported. If the training regimen contained exercises which appear closely related to depth jumping procedures followed in the study, then this could have a significant bearing on the results of the study.

Blattner and Noble (1977) studied the effects of isokinetic and plyometric training on vertical jump performance. Forty-eight volunteer males were randomly assigned to one of three groups. The treatment period was eight weeks long with the isokinetic group performing 3 x 10 leg press exercises on the Model 16 BX "Leaper" by Mini-Gym Inc., while the plyometric group performed depth jumps from 34 inches with weights added at regular intervals. The third group was the control group. Results showed both training groups improved significantly on vertical jump, however, no significant difference existed between training groups.

Polhemus, Burkhardt and Patterson (1978) studied the effects of plyometrics with ankle and vest weights on conventional weight training programs. Twenty-seven male track and field athletes and thirty-one women athletes from basketball and swimming were subjects in a six week study. Subjects were randomly divided into two groups. Group 1 performed plyometrics and weight training and Group 2 lifted weights. Treatments were three times per week. Subjects performing plyometrics used vest weights amounting to 10-12% of body weight. Subjects were pre-posted using vertical jump, standing long jump and 40 yard dash. The experimental group showed vast improvements over the control group, when both men's and women's results were compared.

Polhemus and Burkhardt (1980) conducted a study using one hundred and three male collegiate football players. Eighty-nine completed the study. Over a six week period the effects of plyometrics on strength gains were studied. The study involved three groups with Group 1 using conventional weights with no plyometrics. Group 2 used conventional weights with plyometrics but with no weight added. Group 3 used conventional weights and plyometrics with ankle and vest weights added. Pre-post-tests were conducted using bench press, power clean, squat and military press. Group 3 showed gains 50% greater than Group 1 while Group 2 showed gains of 30% over group 1.

Scoles (1978) conducted a study to determine the effects of depth jumping on the vertical jump and standing long jump of adult, college males. Subjects were randomly assigned to three groups: G1:depth jump; G2:flexibility; G3:control. Subjects were pre-post-tested in vertical and standing long jumps. Of the 34 subjects who commenced the study 26 completed the eight week training period. Participants in G1 jumped from a height of 0.75 m twice per week with 20 jumps per session. Group 2 was engaged in stretching hamstrings, quadriceps and lower back muscle groups twice per week for the eight weeks. The control group took no part in any treatments. Results revealed that neither treatment caused improvement at an F ratio significance level of .05. Improvements were noted though. Mean improvement levels for G1 were 4.3% vertical jump and 2.95% in standing long jump. Group 2 improved 1.3% in vertical jump and 0.33% in standing long jump. The control group 1.8% in vertical jump and 1.99% in standing jump.

Adams (1984) conducted a study in order to determine the effects of depth jumping on muscular leg strength and muscular leg power. There were one hundred and seventy-seven male and female subjects, from junior and senior high school, with ages ranging from 12 to 17 years. Subjects were divided into six groups. Each group performed depth jumping from a different height. Groups 1 to 4 performed depth jumps from .75 m, 1.5 m, .61 m and 1.22 m respectively. Group 5 was a control non-jumping group while group 6 participated in various activities including jumping. The treatment involved 20 depth jumps performed three times per week for seven weeks. Pre-post-tests were conducted using vertical jump, standing long jump and isometric leg strength using a cable tensiometer (Pacific Scientific Co.). The results showed that depth jumping from heights of .75 m to 1.5 m does not significantly develop muscular leg power. There were however, gains as shown in vertical jump performance but not by standing long jump. There were significant differences, at the .05 level, in gains in muscular strength between groups 1 and 2 and between groups 2 and 4. This would suggest that jumping from higher heights results in greater gains in strength.

Maneval et al., (1984) divided 75 male and female volunteer college-age students into three groups in an attempt to determine the effectiveness of two days per week of depth jump training as opposed to three days per week of depth jump training. The treatment period was ten weeks and the investigators studied whether or not there was a plateau effect on improvement during the treatment period. Group 1 performed depth jumps three days per week while group 2 performed depth jumps two days per week. Group 3 was the control group. Groups 1 and 2 were required to perform 20 consecutive depth jumps from 0.75 meters and 20 consecutive depth jumps from 1.10 meters during each treatment. The Sargent Chalk Jump was the performance test. A pre-test was conducted followed by post-test after 10 weeks. The results showed that the three groups improved significantly. The control group improved 1.27 cm. while the other two groups improved an average of 7.26 cm. The gain in the control group was attributed to learning. The two days per week group showed significant gains over the three days per week. The results of the measures taken during the treatment period showed that no plateau was wrenched in performance in the vertical jump test. Therefore, the subjects showed improvement during the treatment period.

The results of the studies presented are mixed. Polhemus et al., 1978 and 1980 showed that depth jump training combined with weight training or vest weights showed significant gains in vertical jump and strength development. The studies by Clutch et al., (1983), Blatner and Noble (1977) and Scoles (1978) showed no significant differences in relation to the respective performance measurements. Adams (1984) showed significant gains in isometric leg strength in depth jumping from high heights over low heights. Maneval et al., (1984) not only found that depth jumping improved vertical jump performance but also found that two days per week was superior to three days per week.

The differences in results clearly indicated the need for further research in the area. Perhaps treatment periods of greater that 10 weeks should be used. There are indications that depth jump training improves vertical jump performance and performance of static and dynamic strength tasks. This may suggest that an influence on power development and strength development. This investigator would suggest that more sophisticated investigations be conducted until these conclusions be drawn. The differences in results may also indicate the need to attack the question of the effectiveness of depth jumping from a different standpoint.

Long Jump

Ballerich (1973) described the kinematic features which contribute to performance in the long jump. The jump was divided into the run-up, take-off, flight and landing. The features of the run-up were length of stride and foot position. Maximum inclination of the knee of the take-off leg, take-off time, mean angular velocity and reduction of horizontal velocity were required with respect to take-off. Characteristics of flight were the angle of projection, flight duration and respective movement of body parts. Position of the body, height of the center of mass relative to contact point were features of the landing. The duration of the landing phase was also important.

Hay (1985) outlines a number of considerations in regard to the take-off in long jump. The take-off distance is related to the physique of the athlete and is the horizontal distance between the front edge of the take-off board and the athlete's center of gravity at the instant of take-off. Flight distance is governed by motion of projectiles - speed, angle, height of take-off and air resistance. Angle of take-off is determined by a combination of horizontal speed and vertical speed.

Bosco et al. (1976) used a force plate to determine the variations in ground reaction forces during long jump take-off of four national level long jumpers from Finland. The displacement of the center of gravity of each subject, during the jump, was determined using cinematography. The take-off was divided into two phases for consideration of results obtained from the force plate. There were a number of results reported, however those relating to take-off will be considered here. The results showed that contact time correlated negatively (-0.89) with length of jump. There was a negative correlation (-0.87) between vertical velocity and reduction in horizontal velocity during the first half of contact time. There was a high correlation (0.90) between vertical velocity and reduction of horizontal velocity during the second contact phase. Vertical velocity during the second contact phase showed a low correlation with distance jumped. Good jumpers were characterized by minor reductions in horizontal velocity and by increases in vertical velocity during the first contact phase. Cinematographic analysis of the displacement of the center of gravity of poor jumpers showed a failure to raise the center of gravity during the first contact phase and a longer time period to reach maximum vertical velocity.

Karayannis (1978) conducted a cinematographic analysis of the first nine places in the 1974 NCAA Long Jump Championship. The speed of the camera (Photo-Sonics 1P 16 mm) was 100 frames per second. The suggestion was made that film speed of between 200 and 500 frames per second is required for more detailed analysis of the take-off foot contact. Six fix points were selected on each subject, ear and shoulder joints, waist and hip joints. Final velocities were in the range 9.83 meters/second or 32.42 feet/second and 11.87 meters/second or 38.93 feet/second. One of the jumpers showed final velocity of 14.45 meters/second or 47.4 feet/second, however, this could be accounted for in a change of film speed between 90 and 85 frames/second. A loss of from 4.9% to 13.3% was found between final velocity and take-off velocity. The best jumpers took less time to gain maximum flexion of the knee of the take-off leg by comparison with other jumpers. The results also showed that final velocity was of less importance than the ability to display the greatest dynamic effort in the least amount of time in contact with the take-off board. The film analysis showed a wide variety of foot placement. Foot sliding tended to increase when the heel contacted the ground first and reduced as foot contact tended from heel-ball to flat foot contact. The range of sliding for heel-ball and flat foot was .62 to 1.2 inches and up to three inches for heel first contact. The longer the sliding the greater the loss of horizontal velocity.

There were a number of limitations to the study. Neither the weight nor the height of the subjects was obtained. The position of the jumper's leg in the air was estimated for four or five frames as a judge was seated on the pit side of the board between the camera and the jumper. The camera was moved several times between jumps. Over the several days of filming the projector table and mirror tables could have been moved.

Ramsey (1973) presented the results of a digital computer simulation (Burroughs B5500) in order to determine the rotational effects produced by angular momentum during three styles of long jump (hang, sail and hitch kick styles). A nine segment, hinge connected system of rigid bodies was used with the function of arm and leg action being derived from actual film record of the three jumping styles. The United States Air Force mean man was used as the base for this "athlete". According to the simulation, a distance of 21.2 ft. would be jumped at take-off velocities of 10 ft/sec. vertical and 25 ft/sec. horizontal.

Eight volunteer collegiate and interscholastic long jumpers were the subjects used by Bedi and Cooper (1977) in order to determine the direction of angular rotation of the body in long jump, by measuring changes in angular momentum produced at take-off. Kinematic data were collected using a 16 mm Locom Camera (Redlake Labs Inc., CA) fitted with a 25 mm lens and positioned 51.2 feet from the center of the take-off board. Film speed was 99 frames/sec and the film was Tri-X reversal (ASA200). A clock and stroboscope were positioned in the field of view to ascertain time and synchronization of force and film data. The force plate was constructed by the Indiana University Electronics Shop. The range of jumps recorded was 19.25 ft. to 21.30 ft. Immediately prior to take-off board contact the mean approach run velocity was 26.6 ft./sec. The mean maximum vertical force exerted in the take-off phase was 930 lb with the best performers exceeding this by 100 lb. The range of take-off contact time was 0.11 to 0.12 sec. for good performers while poorer performers ranged from 0.13 to 0.15 sec. The mean take-off angle was 24.2 deg. from the horizontal while the take-off angle for the poorest jumper was 17 degrees. The most successful jumpers spent less time in contact with the take-off board. The suggestion was made that vertical and horizontal forces are important to the success of the jump as well as the horizontal velocity.

A tri-axial arrangement employing three high-speed 16 mm cameras with a 3-dimensional force-platform were used by Cooper et al., (1973) to study three long jumpers from the Indiana University track team. No information was provided regarding manufacturer of instruments used. The jumper with the longest jump shortened his last step at take-off and spent the least time in contact with the take-off board. The longest jumps were also associated with largest vertical impulse exerted on the take-off board and greatest breaking impulse. Increasing the breaking force may be essential in maximizing vertical velocity. In order to increase the distance of the jump the horizontal and vertical velocities should be maximized. All jumpers experienced a slight reduction in horizontal velocity in the last few steps of the approach run. The angle of projection, as determined from the center of gravity at take-off, appears to be no greater than 31 deg.

Plagenhoef (1973) used his own computer program to obtain segment angular velocities and accelerations, forces of motion, and joint movements of force for the 8.90 m world record long jump of Beamon, the 8.24 m winning long jump by Williams in the 1972 Olympic Games and the 6.70 m jump of a college jumper. No information was supplied regarding the filming of the jumps. The suggestion was that Beamon timed the acceleration and deceleration of all body segments during take-off, to perfection. The results showed that Beamon and Williams ran down the runway about 4ft/sec. faster than the college jumper. The angle at the knee when the take-off board was contacted by Beamon was

160deg. while the knee angle for the other two jumpers was 175deg. Beamon then closed the knee angle to 142 deg. while the other two were closer to 150 deg. The thigh of the free leg attained a maximum absolute velocity of 28.6 rad/sec. for Beamon with Williams at 18.2 rad/sec. and the college jumper at 18 rad/sec. The same thigh experienced maximum absolute deceleration of 575 rad/sec. for Beamon, 525 rad/sec. for Williams and the college jumper at 253 rad/sec. The respective angles when maximum deceleration of the thigh occurred were 26 deg., 35 deg., and 39 deg., from the horizontal. Beamon achieved take-off by producing resultant forces through an angle of 26 deg. to the horizontal (all three jumpers had a take-off angle of about 24 deg.). This angle was calculated at the center of gravity. Both Williams and the college jumper gained good vertical lift, the college jumper to a lesser extent. Williams failed to achieve sufficient horizontal forces while the horizontal forces achieved by the college jumper were detrimental to the jump.

Ballriech (1973) presented the results of a study of 60 long jumpers. There were three groups with distances jumped ranging from: G1:7.22-6.49 m; G2: 6.74-5.98 m; G3:5.95-5.00 m. The kinematic features of run-up, take-off, flight and landing were obtained using two Hycam 16mm slow-motion cameras. The film speed was 200 frames/sec. Dynamic features of take-off were determined by Kistler

Instrument AG. 3-component force-plate. The kinematic features of the take-off were recorded. The final mean take-off velocity for each group was: G1:3.5m/sec.; G2:3.2m/sec.; G3:3.1m/sec. Horizontal velocity tends to be reduced by horizontal impulse. Increases in vertical velocity were more responsible for greater distances than increases in horizontal velocity. The better performers were better able to change their downward acceleration into upward acceleration in the early stage of the take-off. This enabled the attainment of higher vertical velocity.

Siluyanov (1977) correlated data from six long jumpers in order to determine approach run speed and ground reaction forces. Two force-platforms were used with two subjects to gather data and to construct regression lines for comparison with regression lines of four long jumps from three different long jumpers. The results showed that there were different regression lines even if approach run speeds were the same for different jumpers, and with different distances jumped with the same approach speed. A very high correlation was found between distance jumped and the magnitude of the ground reaction forces at the instant of initial knee joint extension. The ability to increase take-off force as approach speed is increased will result in greater distances.

The review has revealed a number of basic elements in long jump take-off that contribute to maximizing distance jumped. Reduced contact time with the take-off board correlates highly with distance jumped. Reduction in horizontal velocity prior to take-off should be kept to a minimum. Vertical velocity should be maximized as early as possible in the take-off with minimal reduction in horizontal velocity. A number of other related aspects of long jump take-off were reviewed, however, for the purposes of this study these seem most applicable.

CHAPTER III

METHODOLOGY

Sample Description

Six male long jumpers volunteered to participate in this study as subjects. All were members of the Oregon State University Track and Field Team. All were involved in the track and field program from the beginning of the academic year in 1984 until the dates of data collection. Subjects were tested by a qualified medical practitioner from the Student Health Service at Oregon State University and were certified not to have any physical limitations that would adversely affect the data collection. Informed consent was obtained from all subjects and approval from the Oregon State University Board for Protection of Human Subjects was granted.

Table 2. Description of Subjects

	X	SD	Range
Age (yrs)	20.33	1.37	19-23
Height (cm)	177.50	3.10	173-183
Weight (kg)	75.90	4.12	70.31-83.46
Body Fat (%)	8.08	2.20	4.51-10.46

Training Procedures

Four weeks prior to filming, the subjects submitted to six practice sessions involving the depth jump procedures. The first three practice sessions were devoted to learning the required kinematic features of the depth jump. Six (6) depth jumps were taken by each subject from the platform height of 0.75 m during each of the three sessions. The fourth practice session included the performance of three (3) depth jumps from the height of 0.75 m and three depth jumps from the height of 1.10 m by each subject. Practice sessions five (5) and six (6) each involved six (6) depth jumps performed by each subject from the platform height of 1.10 m. Performance of the required kinematic features for the depth jumps was reinforced during each practice session by the investigator. Subjects followed their normal training regimen for the long jump, with practice sessions twice each week and occasionally three (3) times each week during the nine (9) months prior to data collection.

Data Collection Procedures

Experimental Set-up

The long jump take-off board served as the depth jump landing area during all trials. The 0.75 m high platform and the 1.10 m high platform were placed 0.50 m from the center of the long jump take-off board. A meter stick was placed in the viewing area on the side of the runway to serve as a scale device. The camera was placed on the opposite side of the runway perpendicular to and 6.38m from the center of the long jump take-off board. The center of the platform was aligned with the center of the long jump take-off board. The platform was removed for filming of the long jump.

Instructions to Subjects and General Protocol

Prior to the data collection subjects underwent a normal pre-competition warm-up consisting of 20 minutes of jogging and stretching exercises and three acceleration runs over 100 meters. Each subject ran three practice approach runs prior to the long jump trial Immediately prior to filming, joint centers on each subject were marked according to procedures established by Plagenhoef (1975). Subjects were again instructed as to performance requirements. They were instructed to (1) stand on the platform with their feet evenly spaced either side of the center of the platform, (2) step, not jump, from the top of the box and land on the long jump take-off board on both feet simultaneously, (3) then jump as high vertically, as possible, leaving the surface as quickly as possible, (4) draw both arms together behind the body while stepping from the top of the box (see Fig. 1). The

Fig. 1. Subjects were instructed to step, not jump, from the top of the platform, and to withdraw the arms behind the body by extending the arms at the shoulders.

arms would then be ready to swing forward and upward during contact time with the long jump take-off board (see Fig 2).

Each subject was filmed performing a depth jump from two heights, 0.75 and 1.10 meters, the heights recommended by Verhoshanski (1967). Performance of the long jump take-off by each subject was also filmed. One trial per condition was filmed and those trials which were deemed by the investigator to be unsuitable were repeated.

The subjects performed the depth jumps in nonspiked running shoes. These were the shoes regularly used by the subjects for warm-up and for plyometric training.

The investigator established the long jump performance requirement for each subject. This requirement was based upon a calculation of 90% of the best distance jumped by each subject during the previous competition season. Subjects jumped as they would during a regular competition wearing the same spiked jumping shoes. Jumps were measured from the point of take-off with the take-off board.

Data were collected three days after the 1985 Pacific 10 Conference Championships. Two subjects attended the Championships and had two full days rest prior to data collection. The other subjects continued regular training until two days before data collection.

Fig. 2. Subjects were instructed to jump as high vertically as possible, leaving the landing surface as quickly as possible.

Cinematography

Subjects were filmed using a Redlake Locam high speed camera set at 200 frames per second. The lens was an Angenieux 12:1 200 mm. Kodak 7277 4X Reversal film was used. Filming and processing was done by the Oregon State University Photo Services Department. The investigator supervised the filming. Conditions for filming were available light and clear skies.

Data Reduction Procedures

Digitizing Procedures

A 16 mm projector, Model 224A Photo Optical Analyzer of L.W. Photo Inc. was used to project the 16mm film onto the digitizing tablet. Digitizing was conducted on a Cal-comp 9100 Graphics Digitizer. The digitizer was inter-faced with an IBM PC XT microcomputer.

Each trial was digitized commencing 20 frames prior to the initial contact by the subject with the landing surface. In the case of the depth jumping, digitizing continued until the subject had reached maximum height after leaving the landing surface. Ten frames were digit-ized following the long jump take-off.

The sequence of points digitized on each frame was as follows: the top of the meter stick, the bottom of the meter stick, ear lobe, near shoulder, near elbow, near wrist, far shoulder, far elbow, far wrist, near hip, near knee, near ankle, near toe, far hip, far knee, far ankle, far toe.

Computer Analysis

Digitized data were processed on an IBM PC XT microcomputer. Center of mass (COM) data were calculated for each frame digitized. Specific values calculated included: COM height from the landing surface (meters), sagital plane deviation of the COM from the take-off foot (meters), vertical velocity of the COM (meters/second), horizontal velocity of the COM (meters/second), resultant velocity of the COM (meters/second), angle of deviation from the COM in the previous frame (radians). Critical elements of performance - point of initial contact and point of take-off - were recorded in terms of a frame number, as the depth jumps and long jumps were digitized.

Statistical Analysis.

One-way analyses of variance were computed to compare the depth jump from 0.75 m, the depth jump from 1.10 m and the long jump take-off in terms of velocities, contact time, and angle of take-off. The .01 level of confidence was used in retaining or rejecting each of the hypotheses. Tukey's Rho Method for testing significance levels was employed as a subsequent test for significant F values (Campbell et al., 1963).

CHAPTER IV

RESULTS

Kinematics of the Depth Jumps

A number of kinematic features of the depth jumps were analyzed. These features were: lead foot, foot placement during contact time, arm position during descent from the platform, elbow position during contact time, hip descent, hip and knee extension, and head/neck position.

Lead Foot

Subjects were not instructed as to which foot should lead into the depth jump. Subjects 1, 2 and 3 used the right leg as the long jump take-off leg, while subjects 4, 5 and 6 used the left leg. From the depth jump height of 0.75 m, three (3) subjects stepped out from the top of the platform with the long jump take-off leg while the other three (3) stepped out with their long jump lead leg. From the platform height of 1.10 m, two (2) subjects stepped out with the take-off leg while four (4) stepped out with the lead leg. (see Appendix B)

Foot Placement During Contact Time

Foot placement during contact was variable. From the 0.75 m height, two (2) subjects landed with the long jump take-off foot forward of the long jump lead foot, one (1) subject landed with the lead foot forward of the take-off foot and three (3) subjects landed with neither foot forward of the other.

From the depth jump height of 1.10 m, one (1) subject landed with the long jump take-off foot forward of the lead foot, while two (2) subjects landed with the lead foot forward of the take-off foot. Three (3) subjects landed with neither foot forward of the other. Two subjects landed with feet in the same position in both depth jump conditions. In both cases the feet were together.

Arm Position During Descent from the Platform

Subjects were instructed to hyperextend the arms at both shoulder joints simultaneously while stepping from the top of the platform. From the platform height of 0.75 m, three (3) subjects descended with arms flexed at the elbow. One (1) subject began the depth jump with both elbow joints in full extension behind the body, with flexion at the elbow joints occurring during the descent. One (1) subject commenced flexion at the elbow 0.035 seconds before initial contact. One (1) subject maintained extension at the elbow joints during the descent.

From the platform height of 1.10 m three (3) the subjects descended with the elbow joints in flexion. One (1) subject immediately flexed the arms at the elbow joints during the descent while another completed flexion at the elbow 0.017 seconds before initial contact with the ground. Only one (1) subject repeated the same arm action during descent from both depth jump heights.

Two (2) subjects commenced flexion of the arms at the shoulders at almost the same time during both depth jumps. From the 0.75 m platform, one subject flexed the arms at the shoulders 0.005 seconds prior to contact and 0.009 seconds prior to contact from the higher platform. The other subject began flexion at the shoulders 0.037 seconds and 0.037 seconds after initial contact from the depth jump heights of 0.75 m and 1.10 m respectively. One (1) subject initiated arm flexion at the shoulders following initial contact during both trials. (See Appendix B)

Elbow Position During Contact Time

Each subject executed a similar arm action during contact time, while performing both depth jump conditions. Five subjects extended the elbow joint during contact time. As the arms swung forward of the body, flexion of the arm at the elbow took place. One subject maintained the arm in a flexed position at the elbow during the depth jumps.

Hip Descent

Five (5) subjects took less time to reach maximum hip descent during the depth jump from 1.10 m than during the depth jump from 0.75 m. One (1) subject took longer to stop hip descent during the depth jump from 1.10 m than in the depth jump from 0.75 m, (see Appendix B)

<u>Hip and Knee Extension</u>

Four (4) subjects took less time to initiate extension of the leg at the knee and of the thigh at the hip during the depth jump from 1.10 m than in the depth jump from 0.75 m. Two (2) subjects took longer to begin the same movement during the depth jump from 1.10 m than in the depth jump from 0.75 m. (see Appendix B)

<u>Shoulder Flexion</u>

Cessation of flexion of the arm at the shoulder tended to take place during the ascent of the depth jump. Five (5) of six (6) subjects ceased this arm flexion earlier during the depth jump from 1.10 m than during the depth jump from 0.75 m. One subject stopped arm flexion at the shoulder during the depth jump from the higher platform but not during that from the lower platform. During the 0.75 depth jump this subject continued to extend the arms at the shoulder. From the same platform height, another subject stopped shoulder flexion and then began shoulder extension. All other subjects, for both conditions stopped shoulder flexion and maintained that position for the remainder of the jump. (see Appendix B)

Head/Neck Position

In all but two trials subjects maintained a similar head position to that of the starting position during the depth jumps from both 0.75 m and 1.10 m. Eyes were looking horizontally into the distance. From the depth jump height of 0.75 m, one subjects' neck was in slight flexion as the arms were swung forward of the hips, during contact time. The head then resumed a neutral position. One subject, from the depth jump height of 1.10 m, looked down after take-off. The head tilt forward was slight.

Kinematics of the Long Jump

Table 3 reflects the mean values related to performances in the long jump. All subjects performed above the level prescribed - 90% of previous seasonal best jump. The shortest distance jumped (5.85 m) was by the subject with the shortest approach run (27.00 m). This subject was also the most inexperienced. The best seasonal performer jumped the longest trial long jump (6.79 m). Standard deviations for long jump performances revealed little variation among distances jumped. The standard deviation for approach run distance was skewed by the short approach run of 27.00 m. An examination of initial take-off foot placement for long jump take-off revealed that five (5) subjects made first contact with the heel of that foot while one (1) subject landed ball of the foot followed by heel. This subject had the fourth best seasonal long jump. Based upon the trial performance this subject jumped 94% of seasonal best, which was the second best performance of the trials. (see Appendix C)

Table 3. Long jump performance (meters).

	X (meters)	SD (meters)	Range (meters)
Long jump seasonal best	6.89	.28	6.30-7.21
Long jump trial	6.43	.30	5.85-6.79
Approach run	34.42	3.75	27.00-38.23

Statistical Treatment.

As expected, approach vertical velocities developed during long jump take-off were less than those from both depth jump heights (Table 5). During the penultimate stride to take-off the center of mass was lowered. The center of mass was then elevated during take-off, thereby increasing vertical velocity. Vertical velocity continued to increase during take-off. This was contrasted by the steep vertical descent during both depth jump conditions enabling development of comparatively higher vertical velocities. Analysis of variance treatment of approach vertical velocities (Table 4) showed significant differences ($p<.01$). Tukey's test of significance revealed significant differences between long jump take-off and both depth jump conditions. Approach vertical velocities developed from the depth jump height of 1.10 m were greater than those from the depth jump height of 0.75 m, with both being greater than those present during the long jump. Examination of the standard deviations for each condition, revealed that results were relatively consistent among subjects.

Table 4. Analysis of Variance for Approach Vertical Velocities

SOURCE:	SS	df	MS	F
BETWEEN:	51.45	2	25.72	93.76*
WITHIN:	4.12	15	.27	
TOTAL:	55.57	17		

*Significant at .01 level.

Table 5. Approach Vertical Velocity (meters/second)

CONDITIONS	X	SD	Range
Depth jump 0.75 m	3.72	.64	2.64-4.21
Depth jump 1.10 m	4.39	.34	3.86-4.78
Long jump take-off	.52	.41	.04-1.19

As a result of the approach run, approach horizontal velocities for long jump take-off were greater than for both depth jump conditions. Analysis of variance (Table 6) showed a significant F value ($p<.01$). Even though mean approach horizontal velocity developed during the depth jump from 1.10 m was somewhat greater than that from 0.75 m (Table 7), the Tukey's test showed no significant differences between them. Horizontal velocities developed during both depth jump conditions were significantly lower than for the long jump take-off ($p<.01$). The range of scores for each condition was small, as shown in Table 7.

Table 6. Analysis of Variance for Approach Horizontal Velocities

SOURCE	SS	df	MS	F
BETWEEN:	339.65	2	169.83	1269.94*
WITHIN:	2.01	15	.13	
TOTAL:	341.66	17		

*Significant at .01 level.

Table 7. Approach Horizontal Velocity (meters/second)

CONDITION	X	S.D.	Range
Depth jump 0.75 m	.91	.14	.76-1.13
Depth jump 1.10 m	.87	.13	.65-1.06
Long jump take-off	10.11	.55	9.68-11.24

As the horizontal component of approach velocity for long jump was significantly greater than that for both depth jumps, the expectation was that approach resultant velocity would be significantly greater as well. The analysis of variance F value shown in Table 8, was significant ($p<.01$). The Tukey's test showed no significant differences between depth jump conditions, however, the test did show that approach resultant velocities for long jump were significantly greater than for both of the depth jump conditions ($p<.01$). There were small differences among subjects for each condition, as revealed by the standard deviations (Table 9).

Table 8. Analysis of Variance for Approach Resultant Velocities

SOURCE	SS	df	MS	F
BETWEEN:	141.79	2	70.89	218.71*
WITHIN:	4.86	15	.32	
TOTAL:	146.65	17		

*Significant at .01 level.

The F value for vertical velocity at take-off (Table 10) was not significant ($p<.01$). Tukey's test revealed no significant differences among all three conditions ($p<.01$). There was a reduction in the vertical component

Table 9. Approach Resultant Velocity (meters/second)

CONDITION	X	S.D.	Range
Depth jump 0.75 m	3.83	.63	2.75-4.29
Depth jump 1.10 m	4.48	.35	3.92-4.90
Long jump take-off	10.08	.54	9.69-11.25

of approach velocity from initial contact to final contact, for both depth jump conditions. The mean difference was 0.45 meters/second for the depth jump from 0.75 m. A

Table 10. Analysis of Variance for Take-off Vertical Velocities

SOURCE	SS	df	MS	F
BETWEEN:	.21	2	.11	1.74
WITHIN:	.92	15	.06	
TOTAL:	1.13	17		

greater decrease resulted for the depth jump from 1.10 m (1.38 meters/second). The standard deviation for long jump take-off (Table 11) was greater than that for the depth jump conditions.

Table 11. Take-off Vertical Velocity (meters/second)

CONDITION	X	S.D.	Range
Depth jump 0.75 m	3.27	.09	3.10-3.37
Depth jump 1.10 m	3.01	.22	2.88-3.43
Long jump take-off	3.08	.31	2.73-3.69

The direction of movement suggested that horizontal velocity would be greater for the long jump take-off than for both depth jump conditions. Analysis of variance for this variable (Table 12) revealed a significant F value ($p<.01$). Tukey's test supported the assumption that a significantly greater long jump take-off horizontal velocity was generated than for both depth jump conditions ($p<.01$). No significant difference in horizontal velocity was found between depth jumps from 1.10 m and 0.75 m. The standard deviations showed small variations among subjects for this variable for each condition (Table 13).

Table 12. Analysis of Variance for Take-off Horizontal Velocities

SOURCE	SS	df	MS	F
BETWEEN:	312.89	2	156.44	776.60*
WITHIN:	3.02	15	.20	
TOTAL:	315.91	17		

*Significant at .01 level.

Table 13. Take-off Horizontal Velocity (meters/second)

CONDITION	X	S.D.	Range
Depth jump 0.75 m	.41	.25	.18-.92
Depth jump 1.10 m	.42	.20	.17-.74
Long jump take-off	9.26	.63	8.81-10.64

Analysis of variance of the take-off resultant velocities (Table 14.) showed a significant F value ($p<.01$). As expected, resultant velocity for long jump take-off was significantly greater than for both depth

Table 14. Analysis of Variance for Take-off Resultant Velocities

SOURCE	SS	df	MS	F
BETWEEN:	174.13	2	87.07	561.42*
WITHIN:	2.33	15	.16	
TOTAL:	176.46	17		

*Significant at .01 level.

jump conditions. Tukey's test also revealed that there was not a significant difference between depth jumps from 1.10 m and 0.75 m ($p<.01$). Relatively small variations among subjects' performances on these trials, were revealed by the standard deviations (Table 15).

Table 15. Take-off Resultant Velocity (meters/second)

CONDITION	X	S.D.	Range
Depth jump 0.75 m	3.30	.07	3.24-3.41
Depth jump 1.10 m	3.05	.21	2.74-3.45
Long jump take-off	9.77	.58	9.29-11.03

Contact time during long jump take-off was less than half that during the depth jumps (Table 17). A significant F value ($p<.01$), however, did not result from the analysis of variance (Table 16). Tukey's test revealed no significant differences among the depth jumps from 1.10 m and 0.75 m, and long jump take-off ($p<.01$). The standard deviations showed very small variations among subjects for each condition, particularly long jump take-off.

Table 16. Analysis of Variance for Contact Time

SOURCE	SS	df	MS	F
BETWEEN:	.09	2	.04	43.34*
WITHIN:	.02	15	1.01	
TOTAL:	.11	17		

*Significant at .01 level

Table 17. Contact Time (seconds)

CONDITION	X	S.D.	Range
Depth jump 0.75 m	.28	.03	.24-.35
Depth jump 1.10 m	.31	.04	.24-.35
Long jump take-off	.15	.01	.14-.16

As expected, long jump take-off angles were significantly less than those of both depth jump conditions. Analysis of variance (Table 18) showed a significant F value ($p<.01$) and Tukey's test also showed that take-off angles during depth jumps from 1.10 m and 0.75 m did not differ significantly ($p<.01$). A lesser angle of take-off for long jump than for both depth jump conditions was expected because of the horizontal approach and comparatively higher approach velocities developed during the long jumps. The standard deviations revealed less var

Table 18. Analysis of Variance for Angle of Take-off

SOURCE	SS	df	MS	F
BETWEEN:	16358.74	2	8179.37	497.76*
WITHIN:	246.48	15	16.43	
TOTAL:	16605.22	17		

*Significant at .01 level.

iations among long jump angles of take-off than among depth jump angles of take-off. Descriptive statistics for angles of take-off are shown in Table 19.

Table 19. Angle of Take-off (degrees)

CONDITION	X	S.D.	Range
Depth jump 0.75 m	82.81	4.54	73.52-86.81
Depth jump 1.10 m	81.97	3.89	77.53-86.87
Long jump take-off	18.44	2.31	15.32-22.75

Table 20 represents a summary of the results of the Tukey's test. The asterisk (*) shows the existence of no significant differences. The absence of an asterisk (*) represents significant differences between that variable and the other two variables.

Summary

Table 20. Summary of Significance

Variable	Depth Jump from 0.75 m	Depth Jump from 1.10 m	Long Jump Take-off
Approach vertical velocity	*	*	
Approach horizontal velocity	*	*	
Approach resultant velocity	*	*	
Take-off vertical velocity	*	*	*
Take-off horizontal velocity	*	*	
Take-off resultant velocity	*	*	
Contact time	*	*	*
Take-off angle	*	*	

*No significant differences existed at the .01 level.

CHAPTER V

DISCUSSION AND CONCLUSIONS

Depth Jumps and Long Jump Take-off

Statistical analyses revealed no significant differences among conditions in regard to take-off vertical velocity and contact time. Velocities from the low platform, however were greater than those of the long jump take-off and the depth jump from 1.10 m. The shortest contact time was for long jump take-off, with contact times for the 0.75 m depth jump and the 1.10 m depth jump approximately twice as long. For other variables examined, no differences were shown to exist between the depth jumps from 0.75 m and 1.10 m. Differences existed between long jump take-off and both depth jump conditions (see Table 20).

The major component of approach velocity for both depth jump conditions and for long jump take-off were vertical velocity and horizontal velocity respectively. Angles of approach and distances travelled for each condition contributed to these kinematic features.

Both depth jumps and long jump take-off showed reductions in vertical velocity between initial contact and take-off. Cooper et al., (1973) suggested that, in long jump, increasing breaking forces at take-off results in an increase in vertical velocity and a reduction in horizontal velocity. Similar results were found in this study. The breaking force during jumps from both depth jump heights resulted in reduced vertical velocities.

Mean contact time for the long jump was less than that for both depth jump conditions, even though no significant differences existed. This is a response to the change in direction from approach to long jump take-off being less than the change during the depth jumps from both heights. Lack of significant differences, in this case may have been caused by the method of calculation of contact time or the variance among subjects for each condition.

Depth Jump

Consideration of kinematics of the depth jumps from 0.75 m and 1.10 m showed that in the depth jump from 0.75 m there were greater take-off vertical and resultant velocities and less contact time than for the depth jump from 1.10 m. Even though there were no significant differences between the two depth jump conditions for all variables, approach vertical and resultant velocities were higher while approach horizontal velocity was less during the depth jumps from 1.10 m than during the depth jumps from 0.75 m. Greater eccentric muscular contraction was required to reduce these velocities during contact time during the higher platform depth jump. Take-off angles for the depth jumps from the higher platform were greater than those from the lower platform.

An attempt was made to find a kinematic feature as demonstrated by subjects that corresponded with outstanding performance data. The subject who performed the depth jumps with elbows maintained in flexion recorded the shortest contact time during both depth jumps and the third shortest long jump take-off (.24 sec., .24 sec. .15 sec., respectively). This subject also recorded the second longest trial long jump. The kinematics exhibited by this subject during the depth jumps included early commencement of arm flexion at the shoulder compared to all other subjects, the second shortest period of hip descent, early cessation of arm flexion at the shoulder after surface contact, and the smallest amount of reduction between approach and take-off velocities for the depth jump from 1.10 m. A small increase in take-off resultant velocity over approach resultant velocity was also shown.

The contention of this investigator is that the superior performance of the subject described above resulted at least partially from the shortened moment arm of the forearm with respect to the shoulder. Time taken for arm action was reduced. Considerations such as leg power or leg muscle fiber typing certainly could have also contributed to performance, but they were not investigated in this study.

Long Jump

The ability of athletes to convert some portion of horizontal velocity into vertical velocity during the long jump take-off is a topic of interest. Approach vertical velocities for the long jump take-off during the present study were in the range of 0.04 meters/second to 1.187 meters/second. Approach horizontal velocities were in the range 9.675 meters/second to 11.240 meters/second. When compared with take-off velocities, there was an increase in the range of take-off vertical velocity from 2.732 meters/second to 3.694 meters/second. This suggested that subjects failed to increase the vertical component of approach velocity in the first half of the take-off. Bosco et al., (1976) reported that good jumpers increased vertical velocity in the first half of the long jump take-off, with minimal reduction in horizontal velocity.

To further examine this question the investigator divided the long jump take-off into two phases, with the first phase being up until the point where the center of mass of the subject was above the take-off foot, and the second phase being until the point of last contact with the take-off surface. Examination of these phases revealed that three subjects showed a greater increase in approach vertical velocity during the first phase of long jump take-off, while the other three subjects showed greater increase in approach vertical velocity during the second phase of take-off (see Appendix D). The subjects who increased approach vertical velocity during the first phase of take-off recorded the 1st., 3rd., and 5th. best jumps of the trials. The subject with the longest trial jump registered the largest increase in approach vertical velocity (1.967 meters/second) during the first phase of take-off. This supported Bosco's (1975) suggestion that subjects who increase vertical velocity in the first half of contact time are likely to long jump further.

Horizontal velocity at take-off is also a critically important factor. Approach horizontal velocities assessed during the present study ranged from 9.675 meters/second to 11.24 meters/second, while take-off horizontal velocities ranged from 8.806 meters/second to 10.64 meters/second. Based upon mean values this represented an 8% reduction in horizontal velocity.

One of the subjects executed a trial jump of 6.44 m which was close in length to the computer simulated long jump of Ramsey (1973). Ramsey (1973) suggested that in order to jump 6.46 m (21.2 ft.), take-off vertical velocity of 3.05 meters/second (10 ft/sec.) and take-off horizontal velocity of 7.62 meters/second (25 ft/sec.) is required. The take-off vertical velocity for the subject in this study was 2.732 meters/second and the take-off horizontal velocity was 8.874 meters/second. Comparison with Ramsay's simulation suggested that this subject was not utilizing velocities developed during the approach run. A take-off angle of only 17.096 degrees reflected this problem. Bedi and Cooper (1977) suggested that a take-off angle of 17 degrees is characteristic of a poor long jumper.

Approach resultant velocities ranged from 9.689 meters/second to 11.247 meters/second. Karayannis (1978) reported a range of 9.83 meters/second to 11.87 meters/second for this variable. He also reported the range of loss of resultant velocity from approach to take-off (4.9% to 13.3%). Five of the six subjects in the present study, showed a loss of resultant velocity from approach to take-off ranging from 1.433% to 7.43%. The other subject showed a gain at take-off of 0.67%. These values are considerably less than Karayannis' (1978) subjects and reflects relative maintenance of resultant velocities. This maintenance, though, resulted from the increase in vertical velocities. The mean approach resultant velocity for this study was 10.08 meters/second. Bedi and Cooper (1977) showed mean approach resultant velocity to be less at 8.11 meters/second (26.6

ft/sec.). The range of jumps for this study and the Bedi and Cooper study were similar (5.85 m to 6.79 m and 5.87 m to 6.49 m respectively). This would support the suggestion that the subjects were unable to develop vertical velocity in the first half of take-off. The reason was that, during the penultimate stride, subjects lower and then elevate the center of mass prior to initial contact. Had subjects, in this study lowered the center of mass to a greater degree, the angles of take-off should have been greater and distances jumped correspondingly longer.

Contact time, as measured in the present study, ranged from 0.14 seconds to 0.16 seconds. As stated previously, the distances jumped in this study compared favorably with those recorded in the study by Bedi and Cooper (1977). Bedi and Cooper (1977) characterized contact time for good jumpers as ranging from 0.11 seconds to 0.12 seconds. All of the subjects in the present study were outside this range, and also outside the range designated as poor jumpers (0.13 to 0.14 sec.) except for one subject. The distance jumped (5.85 m, 19.19 ft.) by one subject was at the low end of distances jumped by subjects in the study by Bedi and Cooper (1977). The subject in this study developed the fourth fastest approach horizontal velocity and the lowest approach vertical velocity. In this trial contact time was the longest of that among subjects. Vertical velocities were not developed in the first half of the long jump take-off.

The range of take-off angles in the present study was 15.322 degrees to 22.748 degrees. Bedi and Cooper (1977) reported a mean take-off angle of 24.2 degrees for good jumpers in the range 5.87 meters to 6.49 meters. The mean angle of take-off for poorer jumpers was 17 degrees. Plagenhoef (1973) reported take-off angles of between 24 and 26 degrees, while Cooper et al., (1973) reported angles of projection no greater than 31 degrees. Five of the subjects in this study recorded take-off angles less than 20 degrees, with three being 17 degrees and less. The angles of take-off in this study tend to be closest to those classified as poor jumpers. Considering that velocities were equal to or greater that those of previous studies, the angles of take-off appear to be critical to the improvement in terms of distance jumped, together with increasing vertical velocity during the first half of take-off, for three of the subjects.

Conclusions

The major finding of this study in terms of long jump is that subjects who increase vertical velocity during the first half of take-off, tend to jump further than those who increase vertical velocity in the second half of take-off.

The findings in regard to the kinematics of the depth jumps from 0.75 m and 1.10 m, and long jump take-off would suggest that use of these depth jumps as training procedures would be specific to long jump take-off in terms of contact time and take-off vertical velocity. There is little if any kinematic similarity between the depth jumps and long jump, in terms of other variables examined. Were either of these depth jump procedures to be used to enhance long jump performance the depth jump from 0.75 m appears to be a more appropriate training procedure, since the velocities were greater and contact times shorter than from the 1.10 m height. The values of these variables were also more closely related to those displayed during the long jump, particularly the approach vertical and resultant velocities. While performing depth jumps, concentration on shortening the moment arm at the forearm should cause contact time to reduce further and take-off vertical velocity to increase.

Considering the platform heights used and the variables examined the findings of this study may support the suggestion of Verkhoshanski (1969) that depth jumping from predetermined heights artifically creates the "reactive ability" required in the muscle to reduce contact time with the long jump take-off board. Clearly further study is required to determine the suitability of depth jumping from 0.75 m and 1.10 m as a method of enhancing long jump performance. A more accurate study of contact time is needed.

Recommendations

As the results of this study unfolded, the need for further investigation became apparent. This investigator suggests that the a range of instrumentation be used to obtain comprehensive data on, kinematic and kinetic features of depth jumps and of neuro-muscular function of the leg. Use of high speed cinematography, a force plate, and electromyography could provide the required data related to the following recommendations:

1. The study of subjects performing depth jumps from varying heights using double leg support, landing on a predetermined landing area.

2. The study of subjects performing depth jumps from varying heights using single leg support, landing on a predetermined landing area.

3. Study the relationship between depth jumping from fixed heights with subjects landing on single leg support on predetermined landing areas, fixed distances from the platform.

4. Study the relationship between depth jumping from fixed heights with subjects landing on single leg support on predetermined landing areas, fixed distances from the platform.

5. Varying the above recommendations changing the action of the arms in terms of degree of arm flexion at the elbow during the jump, and commencing the jump with arms in different positions relative to shoulder flexion or extension.

6. Changing the plane of movement from a vertical orientation to a horizontal plane of movement.

7. Analysis of subjects performing a series of jumps, on the ground, using single leg and double leg support.

REFERENCES

Adams,T.M. An Investigation of Selected Plyometric Training Exercises on Muscular Leg Strength and Power. Track and Field Quarterly Review, 1984, 84,4, 36-39.

Bedi,J.F., and Cooper,J.M. Take Off in Long Jump-Angular Momentum Considerations. Journal of Biomechanics, 1977, 10, 541-548.

Ballriech,R. An Analysis of Long Jump. A Model and the Results of a Multivariate Analysis of Kinematic and Dynamic Scores of Jumping Performance. In S. Cerquiglini, A. Venerando, and J. Wartenweiler, (Eds.), Biomechanics III, Baltimore: University Park Press, 1973, 395-402.

Blattner,S.E. and Noble,L. Relative Effects of Isokinetic and Plyometric Training on Vertical Jumping Performance. Research Quarterly, 1977, 50,4, 583-588.

Bosco,C., Luhthanen,P., and Komi,P.V. Kinetics and Kinematics of the Take-off in Long Jump. In Komi,P.V. Biomechanics V-B, Baltimore: University Park Press, 1975, 174-180.

Campbell,D.T., and Stanley,J.C. Experimental and Quasi-Experimental Designs for Research. 1963, Rand McNally.

Cooper,J.M., Ward,R., Taylor,P., and Barlow,D. Cavagna,G.A., Storage and Utilization of Elastic Energy of Skeletal Muscle. Exercise and Sport Science Reviews. 1977, 5, 89-129.

Cooper,J.M., Ward,R., Taylor,P., and Barlow,D. Kinesiology of the Long-Jump. In S. Cerquiglini, A. Venerando, and J. Wartenweiler, (Eds.), Biomechanics III, Baltimore: University Park Press, 1973, 382-386.

Clutch,D., Wilton,M., McGown,C., and Grice,G.R., The Effects of Depth Jumps and Weight Training on Leg Strength and Vertical Jump. Research Quarterly for Exercise and Sport, 1983, 54,1, 5-10.

Chu,D.C. Plyometrics: The Link Between Strength and Speed. National Strength Coaches Journal, 1983, Apr-May, 20-27.

Chu,D.C. Plyometric Exercise. National Strength Coaches Journal, 1984, Jan, 56-59,61-62.

Hay,J.G. The Biomechanics of Sports Technique, 1985, 422-432.

Harayannis,M.A. A Cinematographic Analysis of Long Jump Take-Off of the Best Nine Long Jumpers at the 1974 NCAA Championships, Track and Field Quarterly Review, 1978, 78,2, 17-23.

Plagenhoef,S. A Biomechanical Analysis of Beamon, Williams and an Average College Long Jumper. Track and Field Quarterly Review, 1975, 75,2, 35-40.

Maneval,M.W., Poole III,W.H., Lander,J.L., Kimbrell,R.C. and Hubbard,J. The Effects of Two Ten Week Depth Jumping Routines on Vertical Jump Performance. Unpublished Research. The University of Southern Mississippi, 1984.

Polhemus,R., and Burkhardt,E. The Effects of Plyometric Training Drills on the Physical Strength Gains of Collegate Football Players. National Strength Coaches Association Journal, 1980, 2,5, 14-17.

Polhemus,R., Burkhardt,E., and Patterson,M. The Effects of Plyometric Training with Ankle and Vest Weights on Conventional Weight Training Programs for Men and Women. National Strength Coaches Association Journal, 1978, 2,1, 13-15.

Ramsey,M.R. Significance of Angular Momentum in Long Jumping. Research Quarterly, 1973, 44, 488-497.

Scoles,G. Depth Jumping! Does it Really Work? The Athletic Journal, 1978, 58, 48-75.

Siluyanov,V., and Maximov,R. Speed and Strength in the Long Jump. Legakaia Atletika, 1977, 10,18. Yessis Review of Soviet Physical Education and Sports, 1978, 13,3, 71-73. (condensed).

Verkhoshanski,Y. Perspectives in the Improvement of Speed-Strength Preparation for Jumpers. Track and Field, 9, 11-12, 1966, Yessis Review of Soviet Physical Education and Sports, 1969, 4,2, 28-34.

Verhoshanski,Y. Are Depth Jumps Useful. Track and Field, 12,9, 1967, Yessis Review of Soviet Physical Education and Recreation, 1968, 3,2, 75-78.

Winter,D.A. Biomechanics of Human Movement. New York, John Wiley and Sons, 1979, 7.

APPENDICES

APPENDIX A

Descriptive Statistics for Age, Height, Weight and Percentage Body Fat

SUBJECT	AGE	HT. (cm)	WT. (kg)	%BODY FAT
S1	19	178	72.58	8.36
S2	20	178	77.11	5.78
S3	23	175	70.31	9.47
S4	21	183	83.46	4.51
S5	19	178	75.30	10.46
S6	20	173	76.67	9.87

APPENDIX B

Lead Foot

Subject	Step out from 0.75 m take-off	lead	Step out from 1.10 m take-off	lead
1	X		X	
2	X			X
3		X		X
4	X		X	
5		X		X
6		X		X

Arm Position During Descent (seconds)

Subject	depth jump 0.75 m	depth jump 1.10 m
1	0.030	-0.005
2	0.035	0.000*
3	0.000*	0.017
4	0.005	0.009
5	-0.037	-0.037
6	0.019	-0.014

*Initial contact is considered to be 0.000 seconds.
-Arm action commenced prior to contact.

Cessation of Shoulder Flexion (seconds)

Subject	depth jump 0.75 m	depth jump 1.10 m
1	0.355	0.310
2	0.305	0.229
3	0.320	0.270
4	0.260	0.220
5	0.143	0.106
6	continued flexion	0.238

Hip Descent (seconds)

Subject	depth jump 0.75 m	depth jump 1.10 m
1	0.130	0.106
2	0.135	0.092
3	0.130	0.091
4	0.063	0.108
5	0.097	0.069
6	0.120	0.057

Hips and Knee Extension (seconds)

Subject	depth jump 0.75 m	depth jump 1.10 m
1	0.165	0.134
2	0.155	0.146
3	0.155	0.109
4	0.121	0.133
5	0.111	0.155
6	0.162	0.089

APPENDIX C

Long Jump Performance (meters)

SUBJECT	LJ BEST	LJ 90%	DIS. JUMPED	RUN-UP DISTANCE.
S1	6.86	6.17	6.44	37.88
S2	7.21	6.48	6.79	38.23
S3	7.02	6.32	6.38	35.77
S4	6.30	5.67	5.85	27.00
S5	6.96	6.26	6.71	33.52
S6	6.96	6.26	6.40	34.14

APPENDIX D

Vertical Velocities During the Two Phases of Long Jump Take-off (meters/second)

Order of best jump	Initial contact	Mid take-off	Final contact
3	.867	2.373	2.732
1	.390	2.357	2.922
5	1.187	2.965	3.209
6	.040	1.131	3.045
2	.097	.957	2.864
4	.520	1.704	3.694

Approach velocities for Depth Jumps from 0.75 m (meters/second)

Subject	Vertical	Horizontal	Resultant
S1	4.102	1.126	4.254
S2	4.211	.761	4.279
S3	4.165	.803	4.242
S4	2.635	.780	2.750
S5	3.020	.968	3.172
S6	4.165	1.027	4.290

Approach Velocities for Depth Jumps from 1.10 m (meters/second)

Subject	Vertical	Horizontal	Resultant
S1	4.487	.938	4.584
S2	4.640	.974	4.741
S3	4.780	1.058	4.895
S4	4.578	.813	4.649
S5	3.860	.653	3.915
S6	4.021	.788	4.097

Take-off Velocities for Depth Jumps from 0.75 m (meters/second)

Subject	Vertical	Horizontal	Resultant
S1	3.370	.536	3.413
S2	3.346	.229	3.354
S3	3.224	.299	3.238
S4	3.312	.305	3.325
S5	3.102	.918	3.235
S6	3.246	.181	3.250

Take-off Velocities for Depth Jumps from 1.10 m (meters/second)

Subject	Vertical	Horizontal	Resultant
S1	2.940	.735	3.030
S2	3.069	.353	3.089
S3	3.430	.353	3.448
S4	3.012	.167	3.016
S5	2.883	.637	2.954
S6	2.727	.293	2.743

Long Jump Approach Velocities (meters/second)

Subject	Vertical	Horizontal	Resultant
S1	.867	10.258	10.031
S2	.390	11.240	11.247
S3	1.187	9.980	10.050
S4	.040	9.689	9.689
S5	.100	9.791	9.791
S6	.520	9.675	9.689

Long Jump Take-off Velocities (meters/second)

Subject	Vertical	Horizontal	Resultant
S1	2.732	8.874	9.293
S2	2.922	10.640	11.033
S3	3.209	9.000	9.555
S4	3.045	9.266	9.754
S5	2.864	8.983	9.428
S6	3.694	8.806	9.550

Contact time (seconds)

Subject	Depth jump 0.75 m	Depth jump 1.10 m	Long jump take-off
S1	.280	.314	.143
S2	.300	.338	.151
S3	.284	.298	.137
S4	.253	.354	.160
S5	.244	.239	.151
S6	.347	.305	.158

Angles of take-off (degrees)

Subject	Depth jump 0.75 m	Depth jump 1.10 m	Long jump take-off
S1	80.986	75.943	17.096
S2	86.085	83.449	15.322
S3	84.710	84.137	19.617
S4	84.747	86.867	18.164
S5	73.516	77.527	17.706
S6	86.810	83.887	22.748