ABSTRACT

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The purpose of this study was to examine how landing surfaces used in a depth jumping (DJ) plyometric exercise affected kinematic and kinetic variables. Sixteen male and female college students, who were involved in recreational activities, performed 5 DJ onto a force platform alone (hard landing surface) and a 2.35cm thick mat placed onto the force platform (soft landing surface). The maximum angular position and angular velocity measurements were recorded and analyzed for the trunk segment and knee joint at the greatest point of knee flexion during landing using a video camera and an Ariel Performance Analysis System (APAS). Contact and flight times were established using data collected by a Bertec force platform. The vertical ground reaction forces and the rate at which these forces were generated were collected and analyzed between surface conditions. An alpha level of 0.05 was used in all statistical tests. A t-test was used for all statistical analyses. Results indicated no significant differences in the maximum angular positions of knee and trunk segments at landing ($p = 0.424$ and 0.266, respectively). Angular velocities of the knee and trunk segment at landing were not significant ($p = 0.153$ and 0.243, respectively). The contact and flight times were found to be nonsignificant ($p = 0.263$ and 0.397, respectively). The time to peak vertical ground reaction force was also found to be nonsignificant ($p = 0.224$). From the results, it can be concluded that a soft landing surface, 2.35cm thick, would be as effective at eliciting the desired traits (decreased joint flexion, decreased contact time, and increased flight time) of the DJ exercise as a hard landing surface.

COMPARISON OF HARD AND SOFT SURFACES DURING MAXIMAL VERTICAL JUMPS IN A DEPTH JUMP PLYOMETRIC EXERCISE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Background

In 1972, Valery Borzov, an Olympic favorite, won the men's 100 and 200 meter sprint races at the Olympic Games in Munich, West Germany. He was a young Soviet (Ukranian) athlete who trained with a protocol similar to that of the sprinters in the U.S. Borzov was a graduate student at the Kiev Institute and studied the then current model of sprinting (Wallechinsky, 1988). In order to improve his performance, Borzov had supplemented his sprint training with plyometric exercises (Bobbert, 1990). Since Borzov's victories in 1972, coaches and athletes from other sports around the world have utilized plyometric exercises.

Plyometric exercises are used in the training programs of speed and power based sports. The purpose behind the plyometric exercise is to improve the athlete's ability to efficiently and quickly produce force from a rapid muscular contraction. Specifically, the depth (drop) jump method has been studied (Bobbert, 1990; Scoles, 1978; Steben & Steben, 1981). This type of plyometric exercise has been shown to improve the vertical jumping ability of athletes in such sports as volleyball and basketball (Bobbert, 1990). Steben and Steben (1981) found that middle school students increased their vertical jump height significantly in the high jump after training with the drop jump exercise. Conversely, Scoles (1978) discovered that depth jump exercises did not significantly increase the vertical jumping height of college physical education students. However, Scoles (1978) did note that the subjects showed improvement after training with depth jump plyometric exercises, although the results were not statistically significant.

In 1978, Scoles investigated the effects of depth jumping on the vertical jump and standing long jump. Twenty-six males who were enrolled in university physical education courses volunteered for the study. The subjects performed vertical jump and standing long jump tests prior to and after performing an 8 week training procedure. Subjects were randomly assigned to one of three groups: a depth jump group, a flexibility group, and a control group. The depth jump group (n = 9) trained for 8 weeks and performed 20 jumps off a 0.75 m platform, two times per week. The flexibility group (n = 9) performed hamstring, quadriceps, and lower back stretching sessions two times per week for 8 weeks. The control group (n = 8) participated in pre- and posttesting only. Scoles (1978) found that there was no significant difference in how the depth jump protocol improved vertical jump and standing jump test scores, as compared with the other groups. The depth jump group did show improvements, although these improvements were not statistically significant when compared to the flexibility and control groups. Although not significant, Scoles's study did provide some information that indicated plyometric exercises could improve jumping performance. Perhaps the 8 week training protocol was not long enough or the sample size of the study was too small to show any significance. In order to understand the mechanisms involved in plyometric exercises, the physiology of the muscular work must be studied.

Anderson and Pandy (1993) viewed an increased vertical jump performance, due to depth jump exercises, from a muscle physiology perspective. Anderson and Pandy wanted to provide further understanding as to how elastic elements assisted with muscle force production during vertical jumping. Their primary focus was the storage and utilization of elastic strain energy within the muscles and tendons. The contractile elements (CE), series elastic elements (SEE), and parallel elastic elements (PEE) are the primary facilitators of power and force (Anderson & Pandy, 1993). The elastic elements perform in concert with, and include the elastic properties of the protein myofilaments actin and myosin. The SEE and PEE are comprised of elastic elements, such as the actin-myosin cross bridges, that run throughout the muscle tissue. These components also complement the elastic properties of the tendons during muscular work. After measuring ground reaction forces to determine the jump height of their subjects, and EMG measurements of muscle activity, Anderson and Pandy (1993) concluded that the elastic tissues contributed about 35% of the total energy transferred to the skeleton from all seven muscle actuators. These muscle actuators included the soleus, gastrocnemius, tibialis anterior, vastus lateralis, rectus femoris, biceps femoris, and gluteus maximus of the right lower extremity. This contribution was consistent from the countermovement jump to the squat jump.

The integration of research that evaluates kinematics and kinetics is essential to the overall understanding of which type of plyometric exercises should be used to enhance athletic performance. Steben and Steben (1981) stated in their discussion that plyometric exercises should be specific to the sport or activity in which the individual is training. Aragón-Vargas and Gross (1997) studied the changes in coordination patterns of subjects' segment actions and changes in vertical jump performance. They used kinematic and kinetic data to analyze each subject's jumps. The researchers concluded that motor control patterns were not standard from subject to subject, and the neuromuscular basis for identifying vertical jump performance needed further study (Aragón-Vargas & Gross, 1997). McNitt-Gray, Yokoi, and Millward (1994) noted differences in kinematics and kinetics of gymnasts who landed onto different surfaces from similar heights. The researchers measured forces from mat/platform and feet/platform interactions to observe differences in loading conditions of the leg muscles. They found that gymnasts were able to modify their landing procedures by varying the amount of hip and knee flexion prior to and during landing (McNitt-Gray et al., 1994).

In the past, coaches have advocated using soft landing surfaces for plyometric exercises to reduce the occurrence of injuries to athletes. Injury prevention is the largest concern that coaches have when implementing plyometric exercises. Ideally, a coach would want a landing surface that is soft enough to prevent stress-related injuries but firm enough to allow for the facilitation of the stretch reflex. The time to peak impact force at landing is of the greatest concern. These ground reaction forces (GRF) can be as high as six times the body weight of the individual who lands from a jump (McNitt-Gray et al., 1994). In order to alleviate the possibility of injury, a surface should be used that will dissipate the forces at landing without compromising the primary purpose of the plyometric exercise. The main purpose of this study was to examine the kinematic and temporal variables of a drop jump plyometric exercise, and how these variables were affected by the surface type used for landing.

Need for the Study

McNitt-Gray et al. (1994) stated that gymnasts used different kinematic and kinetic strategies when landing onto surfaces of different elasticity. The subjects landed onto a soft mat (0.12 m), stiff mat (0.12 m), and a force platform from a height of 0.69 m. The top layer of each mat was comprised of 0.035 m thick stiff ethafoam, and the bottom layer was a 0.085m thick polyurethane foam. Ratings of 30 and 100 were given for stiff and soft mats, respectively, in accordance with an Indentation Load Deflection (ILD) Test. They found that the subjects were able to adjust their degree of hip and knee flexion to the stiffness of the matting and force platform surfaces. McNitt-Gray et al. (1994) found statistical significance in greater knee and hip flexion between the no mat condition and the various mat conditions.

The soft matting could be used in plyometric exercises to decrease the likelihood of lower extremity injuries. This could be accomplished if the surface used was effective at dissipating the impact forces at landing. If the matting contains too much elasticity, then the stretch reflex would be compromised. Providing a landing surface with enough elasticity that decreases the likelihood of injuries, dissipates impact forces, and does not affect the kinematic properties of the stretch reflex is important for the coach in training his/her athletes. In performing these exercises, the utilization of elastic energy to enhance the performance of the athletes is compromised. To examine this hypothesis, this study observed the initial contact time on the landing surface, the flight time of the vertical jump, the vertical ground reaction forces, the time to peak vertical ground reaction force, the maximum angular positions, and maximum angular velocities of the trunk segment and knee of each subject at the greatest point of knee flexion when landing onto hard and soft surfaces. Undergraduate and graduate students who were active in some form of recreational activity made up the subject pool.

Statement of the Problem

The purpose of this study was to determine if the effects of the landing surface in depth jumping influenced contact time, flight time, the peak vertical ground reaction force at landing, time to peak vertical ground reaction force, maximum trunk flexion, and maximum knee flexion after landing. Measurements of maximum angular position were recorded at the greatest point of knee flexion at landing. The greatest angular velocity measurements were recorded at initial contact with the landing surface to maximum knee flexion.

Hypothesis

The major hypothesis of this study was that there would be statistical significance between the contact times, flight times, time to peak impact force, trunk segment flexion, and knee flexion analyzed from the hard and soft landing surfaces.

Assumptions

1. The force platform used was a reliable instrument to measure the impact forces applied during the five trials onto each surface, and was calibrated properly.
2. All subjects were truthful when filling out their background information as to whether or not they had performed at the intercollegiate, semi-pro, or professional level of athletics.
3. The subjects performed to the best of their abilities.
4. All the subjects adhered to pretest guidelines.
5. It was assumed that all subjects could perform a vertical jump.
6. All participants were assumed to be healthy adults.

Limitations/Delimitations

1. Subjects were college age (18-25 years) male and female students who attended the University of Wisconsin–La Crosse.
2. Subjects were allowed to wear the athletic footwear of their choice.
3. Time constraints for testing existed due to the availability of the facility.
4. Kinesthetic awareness and proprioception of each subject was different.
5. Subjects were required to land onto an area measuring 40 x 60 cm.

Definition of Terms

Amortization Phase - change in muscle action from eccentric to concentric contraction (Holcolm, Landers, Rutland, & Wilson, 1996).

Contact Time - interval of time that the body spends on the landing surface.

Contractile Elements - thick and thin protein filaments, myosin and actin respectively, that are responsible for the shortening phase of a concentric contraction.

Cross–Bridge Attachment - connection between the "heads" of the myosin cross-bridge and the actin filament during muscle activity (Zatsiorsky, 1995).

Counter Movement Jump (CMJ) - a vertical jump involving significant downward motion of the center of mass of the body prior to upward propulsion (Anderson & Pandy, 1993).

Depth Jump - jumping vertically immediately after landing from a fall or drop from a predetermined height (Young, Pryor, & Wilson, 1995).

Drop Distance - the distance a subject projects downward towards the ground during a depth jump (Young et al., 1995).

Elastic Energy - energy that is transferred and stored in elastic tissues during muscle activation (van Ingen Schenau, Bobbert, & de Haan, 1997b).

Fast-Twitch Fibers - muscle fibers that display high force, high rate of force development, and low endurance (Zatsiorsky, 1995).

Ground Reaction Forces (GRF) - the amount and direction of a force during a body's contact with the ground (Holcolm et al., 1996).

Maximal Voluntary Contraction (MVC) - highest amount of force generated by the muscles during a voluntary concentric contraction (Hortobágyi, Lambert, & Kroll, 1991).

Mechanical Delay - the time difference between the presentation of the stimulus and stimulus response (Bosco, 1997).

Parallel Elastic Elements (PEE) - elastic components of muscle tissue which run parallel to series elastic elements.

Plyometric Exercises - techniques or drills used to enhance performance through neuromuscular training: hopping, jumping, and bounding.

Potentiation - the ability of the musculotendon system to increase its energy through a prestretch (van Ingen Schenau, Bobbert, & de Haan, 1997a).

Rate of Force Development (RFD) - time interval that involves the recruitment of additional motor units to generate a specified force.

Series Elastic Elements/Components (SEE/SEC) - cross-bridges between the actin and myosin filaments and in the elastic properties within the actin and myosin filaments (Herzog, 1997).

Short Range Elastic Stiffness (SRES) - the measure of rigidity in an elastic component or tissue during submaximal loading of a musculotendon complex (Komi & Gollhofer, 1997).

Squat Jump (SJ) - vertical jumps beginning with the body in a static, semi-squatting position (Anderson & Pandy, 1993).

Stretch-Shortening Cycle (SSC) - muscle action consisting of eccentric and concentric phases (Zatsiorsky, 1995).

CHAPTER II

REVIEW OF LITERATURE

Introduction

One of the most widely utilized power exercises for improving jumping ability is the depth jump (DJ). This form of training was introduced to the world by a Soviet track and field coach and scientist by the name of Yerri Verhoshanski (Bobbert, 1990). His prized pupil was Valery Borzov, the 1972 Olympic Games champion in the 100 and 200 meter sprints. Verhoshanski introduced a depth jump training protocol into Borzov's sprint training to stimulate the motor units involved in explosive movements (Bobbert, 1990).

The plyometric exercises Borzov used to enhance his sprint performance tapped into energy stored within the elastic elements of the muscle. Tapping into the stored energy to train the muscles to perform more effectively has been shown to greatly benefit individuals who perform explosive movements. The storage and utilization of this energy is dependent upon the efficiency of the exercise. In order to improve jump performance, an individual must accomplish two tasks; first, increase the muscle's ability to utilize and release energy, and second, improve the coordination of the different muscles (Bobbert, 1990). The stretch-shortening cycle is the only mechanism that satisfies these two requirements.

Stretch-Shortening Cycle (SSC)

The purpose of the SSC is to allow for greater muscular force output during a dynamic exercise. Schmidtbleicher (1992) stated that the final action (concentric phase) of a movement is enhanced by the SSC and produces a more powerful contraction. The SSC is initiated by elongating the muscle (eccentric contraction) and tendon. This is followed by an immediate concentric contraction of the muscle. It is believed that this process not only utilizes the contractile elements but also the stored elastic energy in the tendons and series elastic elements to produce force (Schmidtbleicher, 1992). Herzog (1997) summarized the series elastic elements as being comprised of the actin-myosin cross-bridges, which are responsible for the muscular contractions via the sliding filament theory (Huxley & Simmons, 1971). Three fundamental conditions are required for an effective SSC: a well-timed preactivation of the muscle before the eccentric phase, a short and fast eccentric phase, and a short delay between eccentric and concentric phases (Komi & Gollhofer, 1997).

The sliding filament theory has been widely accepted, as well as the idea that cross-bridges contain an elastic component along with the force-producing cross-bridge head (Herzog, 1997; Huxley & Simmons, 1971). Edman (1997) stated that nonuniform distribution of the lengths of neighboring myofibrils during the elongation phase was responsible for residual force enhancement. The nonuniform staggering of the actin and myosin filaments within the sarcomere accounts for the residual force enhancement during the elongation phase, according to Edman (1997). Edman further identified these regions as being "weak" and "strong". The weaker regions, where there are fewer overlapping filaments, are assisted by the increased elastic energy potential within the

SEE and parallel elastic element (PEE). In this situation the weaker regions are able to produce forces equivalent to the stronger regions. Edman (1997) theorized that residual force enhancement following a prestretch could be representative of a mechanism for improving performance during the stretch-shortening cycle.

Komi and Gollhofer (1997) affirmed that muscle force output could be influenced by the motor output. As stated earlier, the power of the SSC is dependent upon the preactivated, eccentrically stretched musculotendon unit followed by an immediate concentric contraction. The efficiency and activation potential of this reflex is dependent on the stiffness of the musculotendon unit. The high level of stiffness needed in the SSC for an increased energy enhancement is determined by the short-range elastic stiffness (Komi & Gollhofer, 1997). As the authors pointed out, stiffness of the musculotendon unit is not only dependent on the range of motion but also the importance of the stretch-reflex system. A critical amount of tension in the musculotendon unit must be achieved to facilitate the level of activity in the neuromuscular system.

Belli and Bosco (1992) compared kinematic results obtained during an *in vivo* study measuring work performed by the contractile elements of the triceps surae during two series of jumps. The triceps surae was modeled with a contractile component and an elastic component. Measurements of each subject's center of mass, muscular efficiency of positive work, individual series elastic component stiffness, and force exerted on the triceps surae in a series of plantar flexion and rhythmical vertical jumps were collected. Six male athletes served as subjects. The plantar flexion series consisted of maximal plantar flexion with the feet starting from a flat-footed position on the force platform. There was a 0.5 s delay between successive jumps. During the rhythmical vertical jumps, no static joint positioning was maintained between upward and downward movements. The knee and hip joints were fixed with orthopaedic casts to ensure muscle isolation of the triceps surae. All trials were performed on a force platform. Belli and Bosco (1992) reported that work performed by the musculature was dependent upon the SEE stiffness. They also reported when SEE stiffness was lower than the optimal stiffness, the work of the contractile elements decreased, but if the stiffness was too low, then the work output of the contractile elements increased. Belli and Bosco summarized their findings by stating:

> In summary, in stretch-shortening conditions, the efficiency improvement could be explained essentially by storage-reutilization of elastic energy in the series elastic components of the muscle-tendon structure and with less extension by contractile component contraction velocity changes...the strategy to maximize the elastic work depends on the force-velocity characteristics of the movement and that the eccentric-concentric muscle work does not always respond relative to the ankle extension-flexion. (1992, p. 407).

The function of utilizing the elastic energy is to enhance the force production of the musculature. In order to maximize the efficiency of the stretch-shortening condition, the musculature must be lengthened so that the contractile elements are performing to their optimal efficiency.

Anderson and Pandy (1993) hypothesized that lengthening the extensor muscles during a countermovement would lead to an increase in the amount of energy stored in elastic tissues. This energy would then be delivered to the skeleton during the propulsion phase of the jump. Anderson and Pandy intended to provide a better understanding of how elastic tissues enhance muscle performance during vertical jumping. The subjects included 5 young, athletic males who each performed 5 countermovement and 5 squat jumps. The subjects' hands were crossed over the chest to eliminate arm swing. Countermovement jumps were performed from a relaxed standing position. Squat jumps were performed from a deep squat position. The subjects were to jump as high as possible off a force platform and then land back onto the platform. Reflective markers were positioned on the right side at the fifth metatarsal, lateral malleolus, lateral femoral epicondyle, greater trochanter, and glenohumoral joint. Preamplified surface electrodes were placed on the soleus, gastrocnemius, tibialis anterior, vastus lateralis, rectus femoris, biceps femoris, and gluteus maximus.

The analysis revealed that elastic tissues delivered the same amount of energy to the skeleton during countermovement jumps and squat jumps. These results were calculated by observing the peak muscle forces developed and quantifying how mechanical energy was transferred between elastic tissues and the contractile elements. In countermovement jumps only the vastus lateralis and biceps femoris developed larger forces than the other muscle groups as compared with squat jumps. The other muscles were found to be maximally activated only after concentric contraction had begun during the propulsion phase. Anderson and Pandy (1993) reported that increased muscle force in the more proximal extensor muscles during a countermovement jump did not result in a large increase in the amount of elastic energy stored. This failed to explain how elastic strain energy was used during each jump.

Anderson and Pandy (1993) theorized that elastic strain energy can originate from two sources: gravitational potential energy of the skeleton (using gravity to pull the body down), and from the contractile elements that convert chemical energy into mechanical energy. The researchers reported that increased tendon compliance led to significant increases in the proportion of energy delivered from the elastic tissues to the tendon. This finding revealed no significant increases in the total amount of work performed on the skeleton (Anderson & Pandy, 1993). In their concluding remarks, Anderson and Pandy stated that storage and utilization of elastic strain energy led to a more mechanically efficient jump rather than a significantly higher jump. This energy can be lost as heat energy if the elastic components stretch the contractile components instead of transferring energy to the skeleton. They summarized that the countermovement jump did not significantly alter the amount of elastic strain energy that was stored in the skeleton during jumping (Anderson & Pandy, 1993).

The effects of energy utilization in the musculotendonous unit have been summized by van Ingen Schenau and colleagues as follows:

> ...the amount of energy stored in series elastic elements at the start of the concentric phases is not determined by the amount of "negative" work performed but solely by the force at the start of push-off. The counter movement provides the muscle time to build up force prior to shortening. Thus, compared to a condition where no counter movement occurs, more energy is stored in elastic elements at the start of shortening. However, the storage of more energy implies a further elongation of the SEE. At the same origin-to-insertion distance this elongation occurs at the expense of the contractile elements. (1997a, p. 392).

This compromise by the contractile element would cause the work potential to decrease. The result of this would decrease the efficiency and purpose of the stretch-shortening cycle by compromising the effectiveness of the contractile elements. If the contractile elements are lengthened beyond their normal length, then effective attachment to cross-bridges could be compromised. Thus, the stretch-shortening cycle would be ineffective.

In 1981, Bosco, Komi, and Ito examined prestretch speed, prestretch amplitude, force attained at the end of prestretch, and the transition time between eccentric and concentric phases to observe how these variables influenced vertical jump performance. Fourteen well-trained power athletes performed maximal vertical jumps, with and without a countermovement, on a force platform. The variables observed were the amplitude of knee flexion, velocity of the prestretch, the force attained at the end of prestretch, and total mechanical work. Bosco et al. (1981) reported that all work performed during squat jumps was positive while work performed during countermovement jumps contained both positive and negative work. The positive work was performed during propulsion and the negative work was performed during the initial downward phase of the countermovement. The researchers concluded that fast lengthening of the muscle, along with a short amortization phase, was likely to cause the eccentric force to be high. This was in association with increased stiffness of the elastic elements. There was also a negative correlation between force at the end of stretch and transition time. Either the force was compromised to illicit a quick reaction, or the reaction time was compromised due to the increased amount of force applied.

Neuromuscular Control

The primary system responsible for muscle activation is the nervous system. Afferent nerves receive input from the environment and send this information to the central nervous system. From there the signal is processed and sent via efferent nerves back to the muscle. This, in turn, causes the muscle to react to the stimulus. Motor patterns have yet to be fully understood, especially with high-force eccentric exercises (Miles, Ives, & Vincent, 1997).

In order to understand motor pattern functions, Miles et al. (1997) studied maximal velocity movement of a high-force eccentric exercise involving elbow flexion. They hypothesized that motor time rather than premotor time was at the center of mechanical delay after eccentric exercise. In order to test this hypothesis, the researchers observed a triphasic pattern involving flexion at the elbow in the sagittal plane and without weights. The forearm was positioned on a table parallel with the floor. The purpose of the elbow flexion was to move the forearm to a position perpendicular to the table. Electromyography (EMG) was used to measure the muscle activation level of the biceps and triceps of 10 nonweight trained females. Each subject performed these flexions as quickly as possible 50 times (two sets of 25 repetitions). The stimulus, an indicator light, was used to signal to the subjects that they were to perform an elbow flexion. The first measurement was that of the initial flexion of the biceps. The second measurement observed the triceps (antagonists) as they acted in opposition to the biceps. The third measurement observed how the biceps reacted as the flexed arm approached its target position (perpendicular to the table). The EMG information was used to observe changes in muscular activity of the biceps and triceps throughout the study.

Their results demonstrated that motor time, rather than premotor time, was responsible for mechanical delay of the biceps during flexion due to the time delay from initiation of stimulus to activation of the biceps. This was shown in the lengthened motor time and decrease of peak velocity (Miles et al., 1997). This increased motor time was theorized as either being related to fatigue or indicated that injury to muscle tissue was a factor in decreased motor time.

Contrary to these findings, Häkkinen (1993) reported that in high loading exercises, not only is muscle tissue damaged, but neural tissue as well. The protocol used by Häkkinen involved 19 strength athletes who performed 20 sets of one repetition maximum squats with 3 minutes recovery between sets. Häkkinen reported maximal loading of muscles with the entire motor unit pools resulted in decreased explosive force. This was primarily due to fatigue and not from decreased calcium uptake nor an accumulation of lactic acid, as previously hypothesized.

Strojnik and Komi (1998) reported similar results when observing fatigue in maximum intensity SSC exercises. Drop jumps on an incline sled apparatus were analyzed using 12 healthy men. The sled, containing the subject, was positioned 80 cm above the platform. It was then dropped and the subject performed a maximal rebound jump continuously until they could no longer jump within 90% of their tested maximum. From this experiment the researchers concluded that an inability to deliver a series of action potentials with high frequency could lower the rate of force development due to a decreased fusion of muscular twitches.

Vertical Jumping

The fundamental objective of the vertical jump is to achieve the greatest vertical velocity at takeoff (Dowling & Vamos, 1993). There are many factors, such as body type and kinesthetic awareness that affect the outcome of the displacement of the center of mass. Dowling and Vamos (1993), in their study of performance variables between individuals using countermovement jumps, reported that variations in vertical jump performance could be explained by differences in peak power when observing maximum vertical ground reaction forces at takeoff. The study involved 97 young adult volunteers who each performed one maximal vertical jump from a static upright posture utilizing an arm swing. With these data, collected using a force platform, they were able to examine 15 variables related to jump performance. These variables included maximum and minimum ground reaction forces, vertical impact forces, positive and negative power, and positive and negative impulse. Dowling and Vamos (1993) reported that peak power was a good indicator of vertical jump performance. Dowling and Vamos also concluded that maximum force was significantly related to jump height. They calculated jump height using the square of the vertical velocity at takeoff, divided by the acceleration of gravity multiplied by two ($H = v^2/2g$) (Bedi, Cresswell, Engel, & Nichol, 1987). They suggested that strength training be introduced at a high velocity in order to illicit an efficient and maximal vertical jump performance. Training the muscles to respond and effectively utilize the stretch-shortening cycle in a motion that is more performance-specific is the goal of the depth jump.

As mentioned previously, the stretch-shortening cycle (SSC) has been reported to enhance the force potential during muscle activation. The purpose behind the depth jump is to employ and enhance the muscles involved in explosive movements by utilizing the SSC. During depth jump protocol, an individual stands on top of a step or box (platform) at a specified height above the ground. The individual steps off the platform and after contacting the ground immediately performs a maximal effort vertical or horizontal jump (Bedi et al., 1987). Bedi et al. (1987) compared the depth jump performance of 12 male volleyball players and 20 physical education students using different platform heights. They used heights of 0 (countermovement jump), 25, 35, 45, 55, 65, 75, and 85 cm, respectively, for their experiment. Each subject was asked to perform a maximal effort vertical jump after landing on the force platform. The subjects performed five jumps from each height. To ensure that the center of mass was approximately the same at takeoff and landing, the hands were positioned on the hip during the entire jump. The jump performance of the physical education students increased and peaked when the platform height reached 55 cm. Data for the volleyball players found no patterns of jump performance improvement or regression during the depth jump trials. Bedi and colleagues (1987) reported that jump performance did not significantly increase with the increased height of the depth jump. The data also suggested that volleyball players jumped the highest during a countermovement jump. This was assumed to occur due to a performance accommodation. The vertical jump height was calculated by measuring the time spent in the air. The equation used for calculating the jump height from time in the air was: $H = V^2/2(g)$ (Hortobágyi et al., 1991), where H is height of jump, V is velocity at takeoff, and g is the acceleration of gravity ($9.81\ m/s^2$).

Bedi et al.(1987) expanded upon the research of Asmussen and Bonde-Petersen (1974). In 1974, Asmussen and Bonde-Petersen studied the effects of energy transferred to the muscles during the preparatory movement preceding a vertical jump. Nineteen subjects performed vertical jumps under five conditions: squat jump, countermovement jump, and depth jumps from heights of 0.233 m, 0.404 m, and 0.690 m, respectively. The metric distance of the jump height was calculated from the flight time. Asmussen and Bonde-Petersen (1974) found that countermovement jumps and depth jumps were significantly better at increasing the subjects' jump height. They concluded from their findings that the elastic structures absorbed negative energy during the countermovement process. This absorption of negative energy allowed for an increase in the storage of elastic energy prior to overcoming the work (Asmussen & Bonde-Petersen, 1974).

Aragón-Vargas and Gross (1997) studied performance-based kinesiological factors that accompanied changes related to vertical jump performance. Observations included the change in coordination patterns of segments and dynamics during the vertical jump. The Aragón-Vargas and Gross (1997) study involved 10 male university students who performed 50 maximal vertical jumps from a position of each subject's choice. The hands of each subject were placed on the hips. The subjects were not allowed practice trials. Trials were performed without footwear and the subjects were allowed to wear only shorts. Reflective markers were positioned on each subject's shoulder, hip, knee, ankle, and toe to record each subject's kinematics. The rest period between jumps was 60 seconds. They found that takeoff velocity determined vertical jump performance. In mentioning the countermovement, Aragón-Vargas and Gross (1997) thought that this lessened the rate of force development by increasing the time necessary to reach maximal force. The researchers also theorized that if a cushioned jumping surface were used, then the rate at which the force developed would increase, thus decreasing the individual's ability to reach maximal force for maximal power output.

In 1988, Dufek evaluated the effects of height, distance, and landing technique on impact forces during landing. A two-dimensional analysis of joint kinematics of the lower extremity during landing was also used. Three male subjects, age 27-30, volunteered for this study. The subjects wore minimal clothing in order for reflective markers to be positioned on the right toe, distal head of the fifth metatarsal, lateral border of the calcaneus, lateral malleolus, lateral femoral condyle, greater trochanter, and head of the humerus. The subjects dropped onto a force platform from three platform heights, 40, 70, and 100 cm using three different landing techniques. These landing techniques involved a relatively stiff knee, slightly flexed knee, and fully flexed knee at landing. Ankle, knee, and hip joint angles were calculated using data collected from videotape analysis. Dufek (1988) found that vertical forces increased with increased drop height and increased knee extension during landing, regardless of the landing technique used. Subjects who landed with a toe-heel strategy showed decreased vertical impact forces.

Landing Surfaces

McNitt-Gray et al. (1994) observed the strategies of gymnasts when landing from a platform 0.69 m in height onto a soft 0.12 m thick mat, a stiff 0.12 m thick mat, and a force platform. The subjects, 10 female and 4 male intercollegiate gymnasts, performed four barefoot landing trials onto each surface. The order of landing surface used was randomized for each subject. Reflective markers were positioned on the subject's greater trochanter, lateral condyle, lateral malleolus, fifth metatarsal, and fifth toe for kinematic analysis. They reported that the gymnasts adjusted their total body stiffness according to the stiffness of the landing surface. McNitt-Gray and colleagues (1994) suggested the gymnasts used a multi-joint strategy to dissipate impact forces. Analysis of hip and knee angular displacements and velocities revealed that this response was noticeably observed at the hip and knee upon landing. The amount of flexion at the hip and knee at landing was used to determine how the gymnasts adjusted their body stiffness. Table 1 summarizes McNitt-Gray and colleagues' (1994) kinematic and kinetic findings.

Gross (1985) investigated the effects of different surface cushioning on the shock absorption properties of the ankle during the landing phase of a vertical jump. Eleven recreational basketball players volunteered for this study. Four of these subjects were classified as forefoot landers, while the remaining seven were classified as heel contacters. Seven reflective markers were placed on the lower right leg: two markers were placed on each side of the calcaneus, one on the Achilles tendon, one on the center of the proximal portion of the tibia, one on the lateral femoral condyle, one on the lateral malleolus, and the last was located on the lateral head of the fifth metatarsal (Gross,

Table 1. Values of Kinematic and Kinetic Variables in McNitt-Gray, Yokio, & Millward (1994)

	Soft Mat	Stiff Mat	No mat
Minimum Knee Angular Position at Landing (degrees)	106.96 ± 5.51	101.71 ± 8.54	90.34 ± 11.35
Minimum Hip Angular Position at Landing (degrees)	106.84 ± 16.63	101.91 ± 16.86	85.03 ± 15.44
Peak Knee Angle Velocities at Landing (deg/s)	568.59 ± 72.67	646.26 ± 74.50	644.22 ± 93.19
Peak Hip/Trunk Segment Angular Velocities at Landing (deg/s)	Not Given	Not Given	Not Given
Peak Vertical Forces at Landing (force/BW)	4.93 ± 0.46	5.11 ± 0.61	3.84 ± 1.21
Time to Peak Vertical Forces at Landing (ms)	64.36 ± 4.97	58.93 ± 6.43	48.00 ± 16.02

1985). Three surfaces were used in this experiment. The first was the cast aluminum surface of the force platform, the second was a 9.0 mm thick tartan rubber surface, and the third was a 13.0 mm thick foam rubber commonly found in running shoe midsoles. The subjects were positioned on the specific surface in an erect position and were told to jump vertically within 90% of their maximum vertical jump height. Three jumping trials were performed on each of the three surfaces with peak vertical forces and ankle kinematics being analyzed. He found that landing surfaces did not produce statistically significant differences in peak acceleration of the ankle joint, peak vertical forces or increased joint kinematics. Gross (1985) reported that peak vertical forces of the heel at contact were significantly greater than for toe contact at landing.

Summary

Anderson and Pandy (1993) concluded that the storage and utilization of elastic strain energy led to a more efficient vertical jump. Contractile elements were also found to produce significant amounts of elastic energy during both squat and countermovement jumps. Belli and Bosco (1992) reported that energy was lost during the storage phase and recoil phase of elastic energy. They also discovered that low cross-bridge stiffness was due to a lower muscle tension in the triceps surae. This decreased the efficiency of the stretch-shortening cycle. Bosco, Komi, and Ito (1981) discussed how greater elastic element stiffness allowed the transition from eccentric to concentric contraction to occur more rapidly. Enhancement of the force output of the musculature was also reported.

Dowling and Vamos (1993) concluded that peak power was a good predictor of vertical jump performance, but high peak ground reaction forces were not correlated with performance. Aragón-Vargas and Gross (1997) also concluded that peak power was the best single predictor of individual performances during vertical jumps. They also reported that takeoff velocity was a significant predictor of vertical jump performance. If power was a good predictor of vertical jump performance, then how can power be harnessed to enhance vertical jump performance?

Asmussen and Bonde-Petersen (1974) and Bedi et al. (1987) reported that vertical jump performance from a depth jump was effective in enhancing vertical jump performance. This exercise utilizes the stretch-shortening cycle to increase the efficiency and force output of the contractile elements of muscle.

The efficiency of the body during the depth jump exercise is determined during the landing phase. McNitt-Gray et al. (1994) stated that the body's rigidity and strategy for landing changed due to the type of surface used for landing. The kinematics of the hip and knee during the landing from the initial drop were reported to dissipate the impact forces at landing. The individual's change in his/her kinematics can influence changes in the neuromuscular system.

The cumulative amount and the intensity level at which the work is performed weigh heavily on the neuromuscular system. Hortobágyi et al. (1991) investigated the reflexive and voluntary response to a stretch-shortening exercise. Their findings suggested that there was a strong relationship with postfatigue that may indicate myotatic (stretch reflex) potentiation as a mechanism for compensating for fatigue. This is in agreement with Häkkinen (1993), Miles et al. (1997), and Strojnik and Komi (1998) who stated that neurological fatigue is the primary factor that controls the ability of the body to perform the vertical jump. The performance of a depth jump relies heavily on the ability of the body to perform efficiently due to the gradual onset of fatigue.

CHAPTER III

METHODS AND PROCEDURES

Introduction

The purpose of this study was to compare how soft and hard landing surfaces affect the kinematics and kinetics of a vertical jump performed during a depth jump. Kinematic data were collected using two-dimensional video based motion analysis. From these data, measurements of the maximum angular position of the trunk segment and knee, at the greatest point of knee flexion at landing, were analyzed. The angular velocities of the trunk segment and knee were recorded from the initiation of contact with the landing surface until the point of maximum knee flexion was attained. Kinetic data were collected using a Bertec force platform. From these data, the time to peak vertical force, peak vertical ground reaction force (VGRF), and temporal variables such as contact time and flight time were calculated. Differences in the kinematics of the trunk segment and knee angle, contact time, and flight time were hypothesized between hard and soft landing surfaces.

Subjects

Sixteen subjects from the University of Wisconsin–La Crosse campus participated in this study. The criterion for participation in this study stipulated that they were presently enrolled at the University of Wisconsin–La Crosse, had no previous or current intercollegiate athletic participation, and did not participate in semiprofessional or professional athletics. The subjects' age range was 18-25 years (19.56 ± 1.80) with a mean height and mass of 173.03 cm (± 10.81) and 70.53 kg (± 13.54), respectively. A metric scale positioned on a wall was used to measure height. These measurement marks were reevaluated for accuracy using a steel tape measure positioned from the floor to ceiling. The mass of each subject was measured using a calibrated Fairbanks Morse scale annually certified for accuracy by La Crosse Scales Incorporated Scales and Systems, La Crosse, WI.

Preparatory Procedures

Approval from the University of Wisconsin–La Crosse Institutional Review Board was obtained prior to commencing with this study. Subjects completed informed consent forms (see Appendix A), a background survey concerning their recreational activities (see Appendix B), and were provided a list of testing requirements (see Appendix C) at the first meeting. The subjects were instructed to refrain from lower body resistance training at least 24 hours prior to testing. They were instructed that the warm-up protocol (see Appendix D), designed by the researcher, was to be performed for 15 to 20 minutes prior to testing. This protocol was similar to the warm up protocol mentioned by Hortobágyi et al. (1991), with additional exercises, intended to decrease the possibility of injury during testing. These instructions were given orally and in written form. The subjects were required to wear athletic shorts, short-sleeved shirts, and the athletic footwear of their choice.

Testing Procedures

Preparatory Set Up and Instruction

Subjects reported to the testing area for further instruction on the day of testing. The subjects' height and weight were measured prior to the warm-up and testing. When the subjects had completed the given warm-up protocol consisting of a 5 minute jog, two sets of 20 parallel squats, and 10 preparatory jumps, the testing began. Reflective markers were applied to each subject's right shoulder, greater trochanter, lateral epicondyle of the femur, lateral malleolus, and on the shoe over the fifth metatarsal. The markers were tracked in two-dimensional analysis frame by frame at a rate of 60 Hz using the Ariel Performance Analysis System (APAS) for kinematic analysis. Each subject was filmed from his/her right side and the researcher assumed bilateral symmetry for all subjects. Subjects were required to drop from a box measuring 40 cm in height onto an area measuring 40 x 60 cm and perform a vertical jump immediately upon contact with the landing surface. Two surface types were used for landing. The force platform, used to collect kinetic data, represented a hard surface, while a 2.35 cm thick foam mat, placed over the force platform, represented a soft surface.

A golf ball was used to measure the stiffness of the force platform and foam matting by videotaping its fall from a specified height. The ball was dropped from a height of 60.6 cm and its rebound height was analyzed using the slow motion selection of a video cassette recorder (VCR). A 60.6 cm wooden ruler with markers placed every 2.50 cm was used to measure the rebound height. The rebound height of the golf ball off of the force platform served as the standard for 100% rebound (50.9 cm). The rebound height of the golf ball from the soft surface was then measured. The height of the rebound off the soft surface was 14.9% that of the hard surface (7.60 cm).

Testing

The testing trials consisted of five consecutive jumps onto the hard surface and five consecutive jumps onto the soft surface. Subjects performed the trials in one of two ways, either landing onto the hard surface then the soft surface (n = 8), or landing onto the soft surface then hard surface (n = 8). This method was used to ensure randomization of the independent variable. The soft landing surface was placed over the force platform prior to recording the kinetic data during the soft landing trials. The subjects were instructed to maintain a position of their hands on the iliac crest. This minimized the use of the arms during the jumping trials. When the subject was ready, he/she dropped off the box onto the surface, located 20.32 cm from the edge of the box to the edge of the landing surface. Subjects were instructed to land and then jump vertically as explosively as possible once they had made contact with the landing surface. No cues from the researcher were given during the trials. The last three trials performed on hard and soft landing surfaces, respectively, were recorded for data analysis.

Measuring Procedures

The force platform used for this study was a Bertec force platform sampling at 1000 Hz interfaced with a computer. It was used to measure and analyze peak vertical ground reaction forces during landing, and the time these forces were generated. These vertical ground reaction forces were normalized to the weight of each subject. These relative values represented the forces generated upon landing in comparison to each subject's body weight. The force platform was also used to calculate the contact time, or the amount of time on the landing surface from initial landing to the last contact at takeoff for the vertical jump. Flight time, or the time in the air from the last point of contact with the landing surface to initial contact with the landing surface during descent from the vertical jump, was also measured using data collected by the force platform. A Panasonic AG-195 video camera was used to collect kinematic data. The kinematic data observed were the maximum angular position of the knee during greatest flexion after landing, and the maximum trunk segment angular position during greatest flexion of the knee upon landing. Peak angular velocities at the hip (trunk segment) and the knee were observed from initial contact with the landing surface until the point of greatest knee flexion was attained. The maximum angular position of the knee was measured as a relative angle, and the maximum angular position of the trunk segment was measured from an absolute angle (see Appendix E). The video camera (Panasonic AG-195) was positioned perpendicular to the plane of action and located 6.49 m from the force platform. The lens was elevated 73.66 cm above the floor. The video camera operated at a rate of 30 frames per second. The shutter speed of the camera was set at 1/1000 second. A halogen light was positioned 10.20 cm above the camera and was utilized for identifying the reflective markers during analysis.

The vertical jump height of each subject was calculated from flight time. The velocity of each subject was first calculated using the equation $V = (G)(T)/2$ (Bedi et al., 1987), where V is the velocity at takeoff, G is the acceleration due to gravity, and T is the flight time. The height of each subject's jump was then calculated using a second equation, $H = V^2/2G$ (Bedi et al., 1987), where H is the height of the jump, in centimeters, V is the velocity at takeoff, and G is the acceleration due to gravity. From these accelerations the jump heights were normalized to relative heights for each subject (see Appendix F).

Data Reduction

An Ariel Performance Analysis System (APAS) was used to analyze the kinematic data used to measure angular position of the knee, angular velocity of the knee, angular position of the trunk, and angular velocity of the trunk at the deepest point of knee flexion, at landing. This system was also used for temporal data analyses to find contact and flight times of each subject. The video image, an analog signal sampled at 30 Hz from the video camera, was converted to a digital signal on the APAS at a rate of 60 Hz. This data sequence was smoothed using a cubic spline set at 1.0 (Wood, 1982). The data were then graphed for joint absolute and relative angular positioning and angular velocities at the hip and knee, respectively.

Statistical Treatment

A paired t- test (Microsoft, 1997) was used on each of the following variables: contact time, flight time, time to peak vertical ground reaction force at landing, peak vertical ground reaction force at landing and propulsion, maximum angular position of the trunk segment and knee at the greatest point of knee flexion, angular velocity of the trunk segment and knee from initial contact with the landing surface until the point of greatest knee flexion, to observe temporal, kinetic, and kinematic differences between surface conditions. The alpha level was set at 0.05.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of this study was to determine if the surface types used in landing from a depth jump significantly affected the contact time, flight time, peak vertical ground reaction forces in landing and propulsion, time to peak vertical ground reaction force, maximum trunk segment flexion, and maximum knee flexion, at the greatest point of knee flexion at landing. The peak angular velocities of the trunk segment and knee were determined from initial contact with the landing surface to the greatest point of knee flexion. The results of this study have pertinent application for those who utilize plyometric exercises in their training protocol. The ability of the muscles to quickly amortize from eccentric to concentric contraction is the primary goal of the depth jump. If a soft surface is as effective as a hard surface for training the athlete, then the soft surface should be utilized in practice to decrease the possible occurrence of injuries. The two surfaces examined in this study provide further information on how landing surface affects the primary objective of the depth jump exercise.

Results

Kinematics

Differences between the means of the angular position of the knee, angular velocity of the knee, angular position of the trunk segment, and angular velocity of the trunk segment at the greatest knee flexion were calculated and compared between landing surface conditions. The maximum positions and angular velocity kinematics of the trunk segment are displayed in Table 2. The paired t-test, used for statistical analysis, found no difference in the maximum angular position of the knee and angular position of the trunk segment at the greatest knee flexion between the surface types ($p = 0.424$ and $p = 0.266$, respectively). The knee angular velocities at the greatest knee flexion were not significant between surface types ($p = 0.153$) (see Table 3.). The trunk segment angular velocities at the greatest knee flexion between hard and soft surfaces were not significant ($p = 0.243$). The maximum knee angular position was plotted against peak angular velocity of the knee in both hard and soft surface results (see Figures 1A and 1B). These best-fit line plots depict the relationship of the maximum angular position of the knee at the deepest point of knee flexion and the angular velocity required for this position.

Table 2. Mean and Standard Deviations of Trunk Segment Angular Kinematics

	Minimum Angular Trunk Segment Position at Landing (degrees)	Peak Angular Velocity of the Trunk Segment at Landing (degrees/second)
Hard Surface	87.26 ± 5.14	11.19 ± 8.25
Range	74.03 - 98.81	0.39 - 38.10
Soft Surface	87.94 ± 5.39	14.98 ± 36.38
Range	75.76 - 101.40	0.13 - 253.50

Table 3. Mean and Standard Deviations of Knee Angular Kinematics

	Minimum Knee Angular Position at Landing (degrees)	Peak Angular Velocity of the Knee at Landing (degrees/second)
Hard Surface	145.46 ± 14.17	67.62 ± 68.87
Range	111.03 - 171.61	9.37 - 310.25
Soft Surface	146.00 ± 13.32	54.67 ± 59.67
Range	97.27 - 166.24	4.31 - 343.43

There was a poor relationship between the position of the knee at landing and the rate at which it reached this position. Three subjects initially hopped, three stepped, and the remaining ten subjects dropped off the box. Differences in the way subjects dropped onto the force platform may have accounted for this poor relationship. These factors could have increased the variability and were affecting the inferential statistics. McNitt-Gray and colleagues (1994) found that the rate of angular velocity of the knee at landing was attributed to the height of the fall. It was assumed that each subject was bisymmetric. The lack of statistical significance of the kinematic results between each surface condition could have also been due to digitizing each subject's right side. Nine subjects dropped off the box with their left foot, while seven subjects dropped off with their right foot. Inconsistency between the subjects leaving the box could have skewed the results as they related to maximum angular knee position and the greatest angular velocity at landing after surface contact.

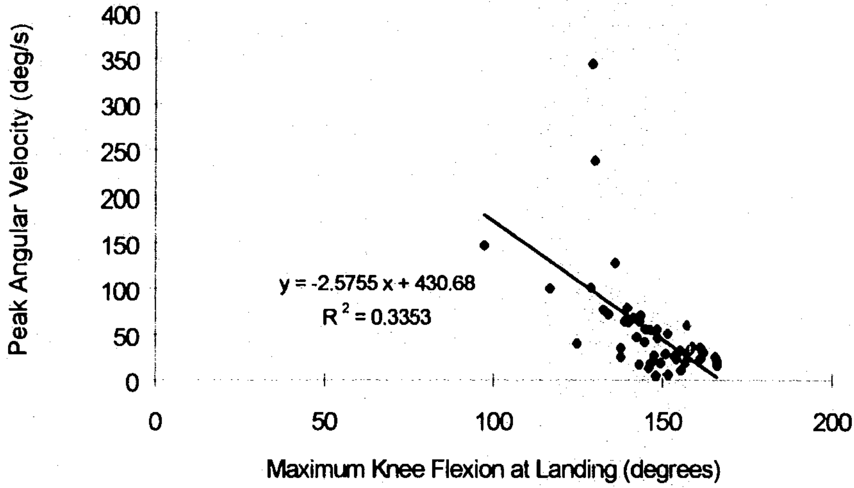


Figure 1A. Peak angular velocity as a function of maximal knee position during flexion at landing for soft landing surface.

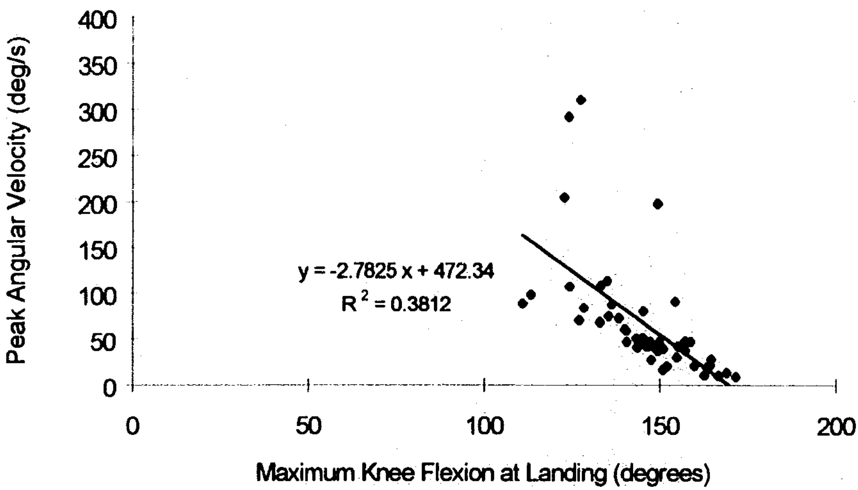


Figure 1B. Peak angular velocity as a function of maximal knee position during flexion at landing for hard landing surface.

Analysis of the maximum trunk segment angular position at the greatest knee flexion were not significant between the surface types (p = 0.266). Peak trunk segment angular velocity at the greatest knee flexion was nonsignificant between the surface types (p = 0.243). The maximum trunk segment angular positions at the deepest point of knee flexion and the trunk segment angular velocities for hard and soft landing conditions, respectively, are represented in Figures 2A and 2B. These figures depict the relationship between the maximum position of the trunk segment, at the greatest knee flexion, and the peak angular velocity of the trunk, from contact to greatest knee flexion. There was a poor relationship between the maximum trunk segment angular position and the peak angular velocity in both surface conditions. This weak relationship may be due the low variability of each subject's trunk flexion at landing. There were three subjects who showed great trunk flexion at landing. These subjects did not deviate their trunk flexion at landing enough to significantly affect the one-tailed p level.

<u>Kinetics</u>

The results of the vertical ground reaction forces were used to calculate the temporal variables of contact time and flight time (see Table 4.). The first point of force application, zero on the y axis and 0.734 on the x axis, served as the start of contact time (see Appendix G). The last point of contact on the force platform served as the termination of contact time and the beginning of flight time. The end point for flight time was established once contact was returned upon landing from the vertical jump. Contact time between the hard and soft surfaces was found to be nonsignificant (p = 0.266). The flight time between the two landing surfaces was also nonsignificant (p = 0.397). The mean heights jumped off the hard and soft landing surfaces were 20.87 cm (± 7.25) and

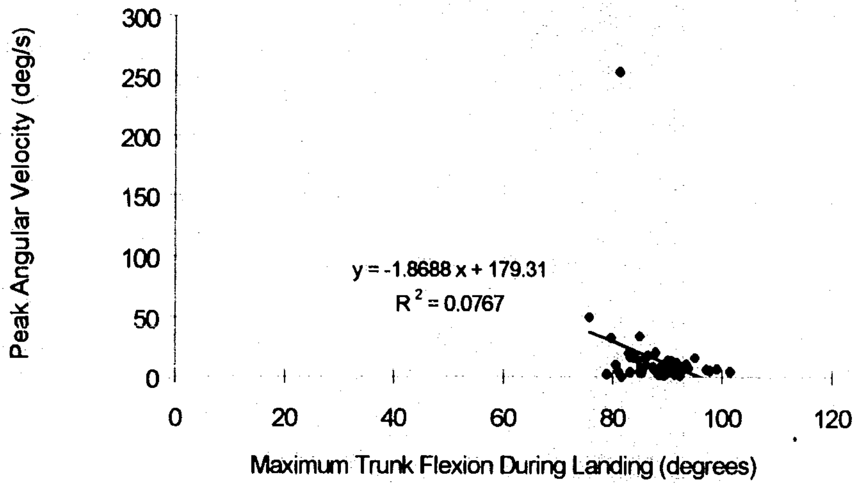


Figure 2A. Peak trunk angular velocity as a function of maximum trunk position during flexion at landing for soft landing surface.

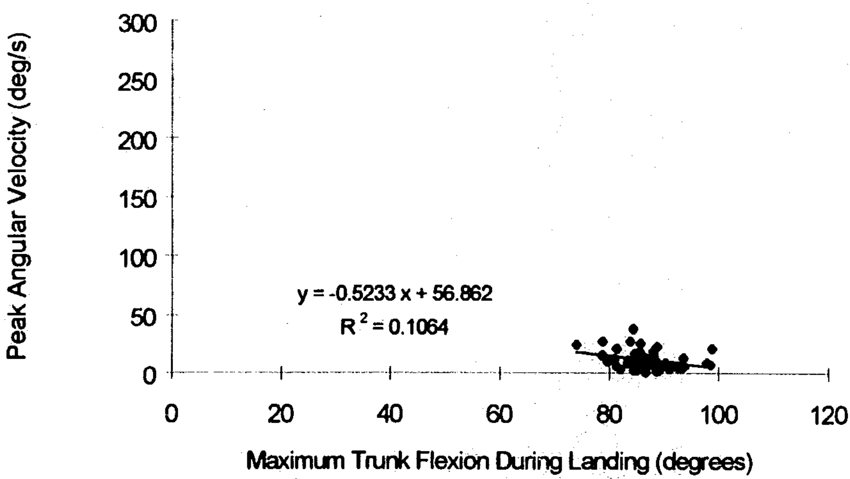


Figure 2B. Peak trunk angular velocity as a function of maximum trunk position during flexion at landing for hard landing surface.

20.89 cm (± 6.61), respectively. Plotting the best-fit line of contact time and flight time for the hard and soft landing surfaces, respectively, yielded no relationship between these temporal variables (see Figures 3A and 3B).

Table 4. Mean and Standard Deviations of the Temporal Variables

	Contact Time (milliseconds)	Flight Time (milliseconds)
Hard Surface	268.13 ± 42.00	406.54 ± 70.78
Range	203.00 – 393.00	281.00 – 553.00
Soft Surface	264.17 ± 35.69	407.73 ± 64.63
Range	198.00 – 397.00	294.00 – 535.00

The vertical ground reaction forces (VGRF) of the body impacting the landing surfaces did not significantly ($p = 0.097$) change with surface type. The time to peak VGRF at landing was not significant between surface conditions ($p = 0.463$). A summary of the VGRF and time to peak VGRF can be found in Table 5. While observing the range of the peaks it should be noted that landing strategies during the depth jump exercise were not controlled. The strategies ranged from toe-heel to flat-footed landings. Dufek (1988) and Gross (1985) both discovered that subjects who landed flat-footed had significantly higher ground reaction forces (GRF). Most subjects landed with the knees extended during the drop from the box. Dufek (1988) reported that increased knee extension at landing significantly increased ground reaction forces in comparison to subjects who landed with a flexed knee. The foam matting on the force platform added an additional 6.25 pounds to the soft surface readings for the GRF. This additional weight was factored out of the statistical treatment and did not affect the overall significance of the results.

Table 5. Summary of Mean and Standard Deviations for Vertical Ground Reaction Forces

	Peak GRF (Absolute) (Newtons)	Time to Peak Force (milliseconds)
Hard Surface	2822.35 ± 198.10	66.04 ± 36.50
Range	1824.26 - 2887.13	26.00 - 203.00
Soft Surface	2775.71 ± 146.41	66.48 ± 34.55
Range	2134.43 - 2891.77	22.00 - 212.00

Discussion

Kinematics

When observing the differences between the hard and soft landing surfaces with the variables of knee angular position and trunk segment angular position at the greatest knee flexion at landing, and peak angular velocities of the trunk segment and knee during contact at landing, no statistical significant differences were found. The sampling rate of the video camera may have been too slow for collecting the kinematic measurements during a movement occurring as rapidly, as with the depth jump. The variability between the subjects could have also accounted for the nonsignificant findings. The variance might be explained by observing the dropping and landing strategies used by the subjects. The subjects were digitized from their right side, however, nine of the subjects dropped off the box leading with their left foot. This may have altered the results of the knee angular kinematics since no uniform method for dropping off the box was employed. The drop style used by each subject was not controlled by the researcher. It was also assumed that each subject was bilaterally symmetric. If subjects showed favoritism for one side of the body at landing this could have affected the kinematic data collection. The initial contact of the feet upon landing from the box was either toe-heel or flat-footed. The subjects did not alter landing strategies between surface types. Subjects two, three, and six landed flat-footed. Noticeable trunk flexion during the drop from the box was observed in these same three subjects. One subject showed the two highest knee angular velocities on both the hard and soft surfaces. This same subject also showed the second highest trunk segment angular velocity on a soft surface, and the third highest trunk segment angular velocity on the hard surface.

The data collected from these subjects could have altered the kinematic results by increasing the variability within the distribution. The results of this study did not find any kinematic differences during landing using a hard surface or a soft foam surface. These results are in disagreement with the findings of McNitt-Gray et al. (1994). They concluded that soft matting allowed the body to decrease flexion at the knee and allow for greater dissipation of the impact forces at landing. Table 6 compares the kinematic and kinetic findings of McNitt-Gray et al. (1994) to the present study.

Table 6. Comparison of Kinematic and Kinetic Results

	McNitt-Gray et al. (1994)			Present Study (1999)	
	Condition				
	Soft	Stiff	No mat	Hard	Soft
Maximum Knee Angular Position (degrees)	106.96 ± 5.51	101.71 ± 8.54	90.34 ± 11.35	145.46 ± 14.17	146.00 ± 13.32
Maximum Hip Angular Position (degrees)	106.84 ± 16.63	101.91 ± 16.86	85.03 ± 15.44	87.26 ± 5.14	87.94 ± 5.39
Peak Knee Angle Velocities (deg/s)	568.59 ± 72.67	646.26 ± 74.50	644.22 ± 93.19	67.62 ± 68.87	54.67 ± 59.24
Peak Hip/Trunk Segment Angular Velocities (deg/s)	Not Given	Not Given	Not Given	11.20 ± 8.24	14.98 ± 36.37
VGRF as a Function of Body Weight (force/BW)	4.93 ± 0.46	5.11 ± 0.61	3.84 ± 1.21	4.22 ± 0.77	4.23 ± 0.74
Rate to Peak VGRF (ms)	64.36 ± 4.97	58.93 ± 6.43	48.00 ± 16.02	66.04 ± 36.50	66.48 ± 34.55

Kinetics

The contact times and flight times were almost identical as depicted in Figures 3A and 3B. The high variability in temporal results can be explained by observing the range of contact and flight times (see Table 3). If the landing surfaces used in this study did not affect the contact time or flight time, then kinematics of the subjects would be assumed to be nonsignificant as the subjects were not observed using different landing strategies

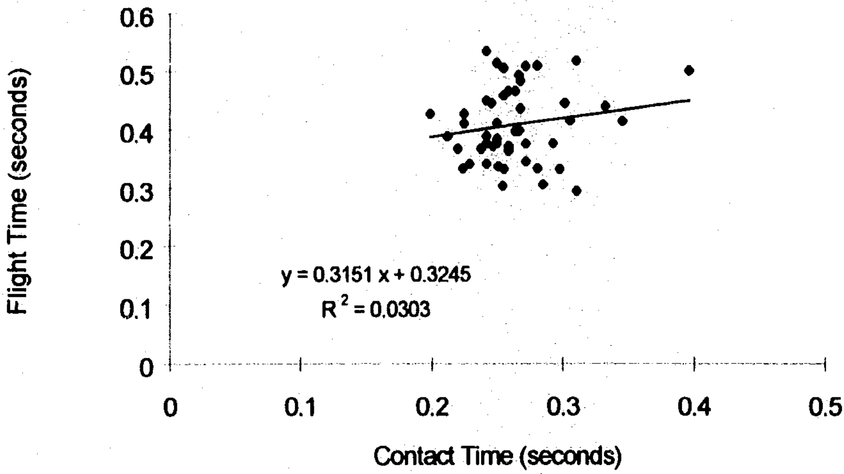


Figure 3A. Flight time and contact time regression plot for soft landing surface.

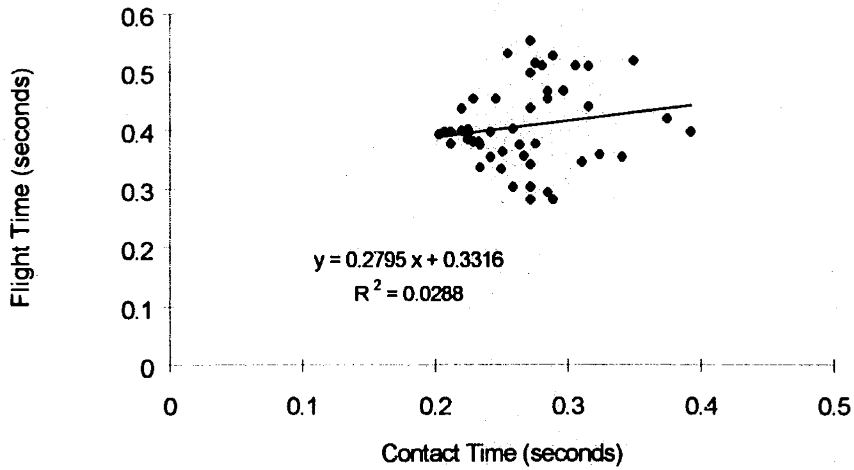


Figure 3B. Flight time and contact time regression plot for hard landing surface.

between surface types. Three different strategies were used to drop off of the box. Two subjects hopped off the box, while two others stepped onto the surface rather than dropping from the box. These strategies did not significantly affect the peak vertical forces applied between surface conditions during the depth jump. The contact and flight times did not show statistically significant differences between the hard and soft landing surfaces ($p = 0.264$ and 0.397, respectively).

It was assumed that different landing surfaces would affect the temporal variables of contact time and flight time. This assumption was not supported by the results of this study. When observing the kinetic variables, the peak vertical ground reaction forces between the surface conditions at landing were not significant (see Table 5). The times to which the vertical ground reaction forces peaked were also not significant between surface conditions (see Table 5). This finding would suggest that soft surfaces that contained enough rigidity or stiffness, such as the type used in the present study, could be used to train athletes during plyometric exercises without significantly affecting the purpose of the depth jump plyometric exercise. However, if the stiffness is decreased or the thickness of the matting is increased, the time to peak vertical ground reaction force would decrease and the kinematics of the hip and knee would be altered (McNitt-Gray et al., 1994). The 2.35 cm thick landing surface used in this study demonstrated how a soft surface could be as effective as a hard surface at providing the favored kinematic, temporal, and kinetic results during a depth jump plyometric exercise.

The velocity and angular positions between the hard surface and soft surface did not show any differences. This is in contrast to the 1994 study by McNitt-Gray and colleagues. They found that the stiffness of the landing surface influenced how their subjects landed from a height of 0.69 m. The minimum angular knee flexion and angular velocity of the knee in McNitt-Gray et al. (1994) were different than the results of this study. The drop height was a major factor between these two studies. A difference of 0.29 m increased the amount of flexion and the angular velocity of the knee at landing in the McNitt-Gray et al. study (1994). These differences could also be related to the thickness of the matting used in their 1994 study. They used mats that were 0.12 m in thickness with ratings of 30 and 100 (Indication Load Deflection Test), compared to the thickness of mat used in this study, 0.0235 m (2.35 cm). This is a ten-fold difference in thickness. Thus, even if no differences were found in this study, it could be argued that the softer landing surface adversely affected the kinematics of the subjects. In this study, however, there were no statistically significant differences shown in the kinematics or kinetics of the landing during depth jump exercises.

The impact forces at landing between McNitt-Gray et al.'s 1994 study and this current study were very similar. These results are shown in Table 6. The time to peak vertical ground reaction forces between the two studies were not statistically significant. The subjects used by McNitt-Gray and colleagues were gymnasts who were familiar with high impact landings. The subjects used in this study were not familiar with dropping from a box and then performing a vertical jump. The gymnasts observed in the McNitt-Gray et al. (1994) study were accustomed to performing jumps immediately after landing from a routine. In competition these gymnasts are required to perform landings that rely on very quick dissipation of forces. The scores received in gymnastics events are dependent on these landings. This would familiarize the gymnasts with applying ground reaction forces very quickly in order to continue their performance. This may explain why the time to peak vertical ground reaction forces at landing were different between studies. Dufek (1988) reported that subjects who landed with a toe-heel strategy from drops off of three different heights (40, 70, and 100 cm) decreased the vertical impact forces at landing. The implementation of this technique along with a soft landing surface could be beneficial to those who utilize plyometric exercises in their training. It should also be noted that the subjects in McNitt-Gray et al. 1994 study performed their landings barefoot, while subjects in this study wore athletic footwear of each individual's choosing. Nigg, Bahlsen, Luethi, and Stokes (1987) reported that midsole hardness did not affect the external peak ground reaction forces in runners. However, the kinematics of the runners were altered due to the change in midsole hardness. In contrast to Nigg et al. (1987), findings of this present study were used to determine that the hardness of the landing surface did not significantly alter the kinematics of the subjects.

The soft landing surface used in this study may have been too hard and erroneously classed as soft. The matting used in the present study for landing was previously used as a wrestling mat. The elastic properties of this mat may have been very much different than those used by gymnasts in the study conducted by McNitt-Gray et al. (1994). This assumption can not be supported since a measurement of durometer for each surface was not conducted in this study.

The present study was similar to that of McNitt-Gray et al. (1994) since kinematic measurements were used to report how landing surfaces affected landing from a fixed height. The time to peak vertical ground reaction force attenuation was significantly different between McNitt-Gray et al. (1994) and this may be due to differences in the selection process of the subjects, varsity athletes versus recreational athletes. However, unlike the 1994 McNitt-Gray et al. study, the present study failed to find any statistically significant difference between a kinematic surface-type or kinetic surface-type relationship between the surface conditions.

Summary

The purpose of this study was to observe the kinematics and kinetics at landing during a depth jump exercise. The results of this study provided evidence that stated there were no statistically significant differences between hard and soft surfaces during depth jump exercises performed from a 40 cm box. The kinematic variables of maximum knee angular position, maximum trunk segment angular position, peak angular velocities at the hip, and peak angular velocities at the knee at the deepest point of knee flexion during landing showed no statistically significant differences between landing on a hard surface versus a soft surface. The temporal variables of contact time and flight time also revealed no significance between surface types. Peak ground reaction forces and the time to which these forces were applied during landing were found to be nonsignificant between surface conditions. These results indicate that training on a soft surface, such as a 2.35cm thick mat, would illicit the desired effects from a depth jump plyometric exercise.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to compare hard and soft landing surfaces used during a depth jumping exercise by analyzing the maximum angular position of the trunk segment and maximum angular position of the knee at the greatest knee flexion at landing, angular velocities of the trunk segment and knee at initial contact with the landing surface until greatest knee flexion, contact time, flight time, peak vertical ground reaction forces, and the time to peak vertical ground reaction forces. Sixteen male and female undergraduate and graduate students at the University of Wisconsin–La Crosse participated as subjects. Each subject completed five jump trials onto both landing surfaces. The last three jumps onto each surface were used for kinematic and kinetic analyses.

The results of this study concluded that there were no statistically significant differences between the hard and soft landing surfaces when comparing the kinematic, temporal, and kinetic variables. A best-fit line plot was graphed to observe a possible relationship between maximum angular positions and angular velocities of the trunk segment and knee, respectively, from the hard and soft landing surfaces (see Figures 1A, 1B, 2A, and 2B). There was a poor relationship found between the angular velocities and the maximum angular position of the trunk segment or the knee at the deepest point of knee flexion at landing.

The temporal variables of contact time and flight time were determined to be nonsignificant between the hard and soft landing surfaces. The peak vertical ground reaction forces and the time to which these peaks were attained showed no differences between surface conditions when a t-test analyzing the paired means of each variable was conducted.

Conclusions

Based on the results of this study, there were no significant differences in kinematic, temporal, or kinetic variables when landing onto a hard or soft surface during a depth jump exercise. The training benefits characteristic of a plyometric exercise may then be provided along with a potential of injury prevention when using a soft landing surface.

The maximum angular positions of the trunk segment and knee at landing were not significantly affected by the different landing surfaces. The angular velocities of the trunk segment and knee at landing were not significantly altered due to no significant change in the contact times on the landing surfaces. A decreased contact time would increase the time to which the angular positions would be achieved. Unlike the study by McNitt-Gray et al. (1994), the subjects in this study did not change their landing strategies when landing onto the hard and soft surfaces.

The purpose of the depth jump exercise is to illicit a quick amortization phase between the eccentric contraction and the concentric contraction of the leg extensors. This amortization phase has been shown to be dependent upon the type of landing surface used and the ability of the subjects to react quickly to the change from downward motion to a vertical jump (Aragón-Vargas & Gross, 1997; Asmussen & Bonde-Petersen, 1974;

McNitt-Gray et al., 1994). The lack of any statistically significant difference between kinematic and kinetic variables indicated that the soft landing surface used in this study would illicit the same training effects as a hard landing surface, while possibly decreasing the likelihood of injuries.

The subjects who volunteered for this study were not collegiate athletes. The participants were active in either weight training, running, or intramural sports. The subjects who performed these depth jumps were not familiar with plyometric or jump training exercises.

The variability between the subjects may have accounted for the large distribution of the data. The mean height of the box, relative to the height of the subjects, was 0.2322, or 23.22 % (± 1.522) (see Appendix F) of each subject's height. The height of the box may have also been threatening to those subjects who were shorter or were unsure as to whether they could jump when they landed after dropping from the box.

Recommendations

Based on the results of this study, it is recommended that future studies observe or control the following:

1. How the subjects dropped from the box. Most subjects dropped off the box, but a few hopped off, and still two more stepped onto the landing surface.
2. Standardize the landing technique used by the subjects. Three of the subjects landed flatfooted, while the remaining 13 landed toe to heel.

3. Standardize the leg used to step off the box. The right view of each subject was analyzed. Seven subjects stepped off with their right foot and the other nine stepped off with their left foot.
4. Control for trunk flexion during the initial descent from the box. Three subjects were observed as having noticeable trunk flexion during descent. These same subjects landed flatfooted.
5. Incorporate more landing surfaces with gradual increases in thickness. This would assist in determining at what surface thickness kinematic, temporal, and kinetic variables were significantly affected.
6. Perform the depth jumps with two footwear conditions: barefoot and with athletic footwear. An analysis of the trunk segment and knee kinematics could then be compared.

REFERENCES

Anderson, F. C., & Pandy, M. G. (1993). Storage and utilization of elastic strain energy during jumping. Journal of Biomechanics, 26, (12), 1413-1427.

Aragón-Vargas, L. F., & Gross, M. M. (1997). Kinesiological factors in vertical jump performance: Differences within individuals. Journal of Applied Biomechanics, 13, 45-65.

Asmussen, E., & Bonde-Petersen, F. (1974). Storage of elastic energy in skeletal muscles in man. Acta Physiologica Scandinavia, 91, 385-392.

Bedi, J. F., Cresswell, A. G., Engel, T. J., & Nicol, S. M. (1987). Increase in jumping height associated with maximal effort vertical depth jumps. Research Quarterly for Exercise and Sport, 58, (1), 11-15.

Belli, A., & Bosco, C. (1992). Influences of stretch-shortening cycle on mechanical behaviour of triceps surae during hopping. Acta Physiologica Scandinavia, 144, 401-408.

Bobbert, M. F. (1990). Drop jump as a training method for jumping ability. Sports Medicine, 9, (1), 7-22.

Bosco, C. (1997) The effect of prestretch on skeletal muscle behavior. Journal of Applied Biomechanics, 13, 426-429.

Bosco, C., Komi, P., & Ito, A. (1981). Prestretch potentiation of human skeletal muscle during ballistic movement. Acta Physiologica Scandinavia, 111, 135-140.

Dowling, J. J., & Vamos, L. L. (1993). Identification of kinetic and temporal factors related to vertical jump performance. Journal of Applied Biomechanics, 9, 95-110.

Dufek, J. S. (1988). The effects of landing on lower extremity function. Unpublished doctoral thesis, University of Oregon, Eugene.

Edman, K. A. (1997). Force enhancement by stretch. Journal of Applied Biomechanics, 13, 484-496.

Gross, T. S. (1985). Effects of surface cushioning on the ankle during vertical jump landings. Unpublished master's thesis, Pennsylvania State University, University Park.

Häkkinen, K. (1993). Neuromuscular fatigue and recovery in male and female athletes during heavy resistance exercise. International Journal of Sports Medicine, 14, 53-59.

Herzog, W. (1997). What is the series elastic component in skeletal muscle? Journal of Applied Biomechanics, 13, 443-447.

Holcolm, R., Landers, J., Rutland, R., & Wilson, G. (1996). The effects of a modified plyometric program on power and the vertical jump. Journal of Strength and Conditioning Research, 10, 89-92.

Hortobágyi, T., Lambert, N. J., & Kroll, W. P. (1991). Voluntary and reflex response to fatigue with stretch-shortening exercise. Canadian Journal of Sports Science, 16, (2), 142-150.

Huxley, A., & Simmons, R. (1971). Proposed mechanism of force generation in striated muscle. Nature, 233, 533-538.

Komi, P. V., & Gollhofer, A. (1997). Stretch reflexes can have an important role in force enhancement during SSC exercise. Journal of Applied Biomechanics, 13, 451-461.

McNitt-Gray, J., Yokoi, T., & Millward, C. (1994). Landing strategies used by gymnasts on different surfaces. Journal of Applied Biomechanics, 10, 237-252.

Microsoft Excel Statistical Program. (1997). Los Angeles, CA: Microsoft Industries.

Miles, M. P., Ives, J. C., & Vincent, K. R. (1997). Neuromuscular control following maximal eccentric exercise. European Journal of Applied Physiology, 76, 368-374.

Nigg, B., Bahlsen, H., Luethi, S., & Stokes, S. (1987). The influences of running velocity and midsole hardness on external impact forces in heel-toe running. Biomechanics, 20, 951-959.

Schmidtbleicher, D. (1992). Training for Power Events, in P. V. Komi (Ed.), Strength and power in sport 1992, (pp. 381-385). New York: National Strength and Conditioning Association.

Scoles, G. (1978). Depth jumping, does it really work? The Athletic Journal, 58, 48-50, 74-76.

Steben, R. E., & Steben, A. H. (1981). The validity of the stretch shortening cycle in selected jumping events. Journal of Sports Medicine, 21, 28-37.

Strojnik, V., & Komi, P. V. (1998). Neuromuscular fatigue after maximal stretch-shortening cycle exercise. Journal of Applied Physiology, 84, 344-350.

van Ingen Schenau, G. J., Bobbert, M. F., & de Haan, A. (1997a). Does elastic energy enhance work and efficiency in the stretch-shortening cycle? Journal of Applied Biomechanics, 13, 389-411.

van Ingen Schenau, G. J., Bobbert, M. F., & de Haan, A. (1997b). Mechanics and energetics of the stretch-shortening cycle: A stimulating discussion. Journal of Applied Biomechanics, 13, 484-496.

Wallechinsky, D. (1988). The complete book of the Olympics. Harrisonburg, VA: Donnelley.

Wood, G. A. (1982). Data smoothing and differentiation procedures in biomechanics. Exercise and Sports Science Review, 10, 308-362.

Young, W., Pryor, J., & Wilson, G. (1995). Effect of instructions on characteristics of countermovement and drop jump performance. Journal of Strength and Conditioning Research, 9, 232-236.

Zatsiorsky, V. M. (Ed.) (1995). Science and practice of strength training. New York: National Strength and Conditioning Association.

APPENDIX A

INFORMED CONSENT FORM

INFORMED CONSENT FORM

The University of Wisconsin – La Crosse
La Crosse, Wisconsin

COMPARISON OF HARD AND SOFT SURFACES DURING MAXIMAL VERTICAL JUMPS IN DEPTH JUMPING

I, ____, agree to participate in the study comparing the effects of hard and soft landing surfaces on the performance of maximal vertical jumps in Mitchell Hall field house at the University of Wisconsin–La Crosse. I understand that this test will measure the contact time on the force platform and the time interval between the takeoff and landing phases during depth jumps. I agree to follow the procedures given to me by the researcher. These procedures include no lower body resistance training (weight training) within 24 hours of testing. I understand that this study will analyze my body's maximal vertical jump height from depth jumps and that this information will be provided upon request. I understand that I may withdraw from this study at any time and will not be penalized for doing so.

I have been informed of any foreseeable or possible injuries during this experiment and am willing to forgo any risks involved. Those risks being: pulled muscle, sprained ankle, injury caused by tripping over a shoelace, falling from the box, soreness, or a broken bone due to an awkward landing during the testing session. I contend that I am in proper physical condition to perform in this study.

The Institutional Review Board for the Protection of Human Subjects (IRB) at the University of Wisconsin – La Crosse has approved this research study. The results of this study may be published or disseminated for future reference.

Concerns regarding any aspect of this study may be referred to the principal researcher (Michael Olson, Rm. 21 or 127 Mitchell Hall, home 782-3111, or work 785-8679) and the thesis advisor (Dr. Marilyn Miller 134 Mitchell Hall, 785-6527). Questions regarding the protection of human subjects may be addressed to Dr. Garth Tymeson, Chair, UW–La Crosse Institutional Review Board (608) 785-8155.

______________________________ Date:______________
Researcher

______________________________ Date:______________
Participant

APPENDIX B

BACKGROUND INFORMATION

BACKGROUND INFORMATION

The researcher (Michael Olson) would like to know what the background experiences have been for each participant concerning exercise habits. If you would please supply answers to the following questions, it would be appreciated. Names are not required for this survey.

1. Gender: Male____ Female______

2. How often do you weight train?:

   a) not at all _______

   b) 1-2 times/week _______

   c) 3-4 times/week _______

   d) > 4 times/week _______

3. How often do you participate in club or intramural sports? :

   a) not at all _______

   b) 1-2 times/week _______

   c) 3 or < times/week _______

4. What sports did you participate in while in high school? ________________________

APPENDIX C

TESTING REQUIREMENTS

TESTING REQUIREMENTS

The major requirements for participation in this study were as follows:

1. No participation in intercollegiate athletics.
2. No participation in semi-professional or professional athletics.
3. Active either in intramural sports or other recreational activities.
4. Currently enrolled at UW-La Crosse as an undergraduate or graduate student.

APPENDIX D

WARM-UP GUIDELINES

WARM-UP GUIDELINES

1. Jog at a comfortable pace around the track in the field house for 5 minutes. This will initiate the rise of the core body temperature.

2. Perform parallel squats in the infield of the track. This dynamic stretch will prepare the leg muscles for the work they are about to perform. The exercise also allows the body to warm-up while focusing on flexibility. Two (2) sets of twenty (20) are to be conducted at a moderate pace.

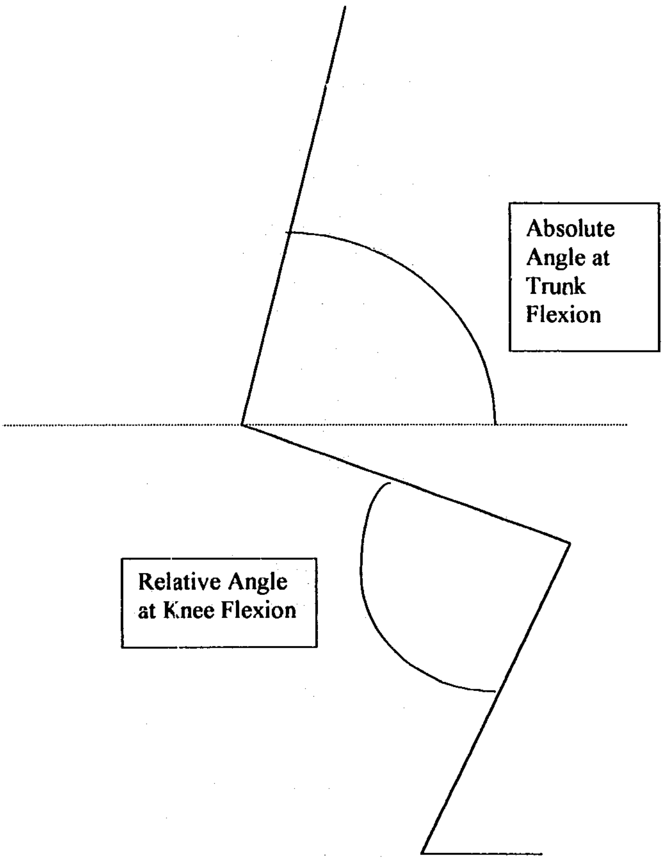
3. One set of five (5) countermovement jumps should be performed to get the muscles ready to perform faster paced dynamic movements. Start from a standing position with the feet shoulder – width apart. Quickly lower the hips as if you were going for a block or a rebound and then explosively jump off the floor. You will be able to use your arms for propulsion in the warm-up, but remember, the arms will not assist you during the testing trials.

4. If needed, other flexibility exercises can be performed prior to testing. Once you are ready we can begin the testing trials.

APPENDIX E

REPRESENTATION OF ANGLE MEASUREMENTS FOR KINEMATIC ANALYSIS

REPRESENTATION OF ANGLE MEASUREMENTS FOR KINEMATIC ANALYSIS



APPENDIX F

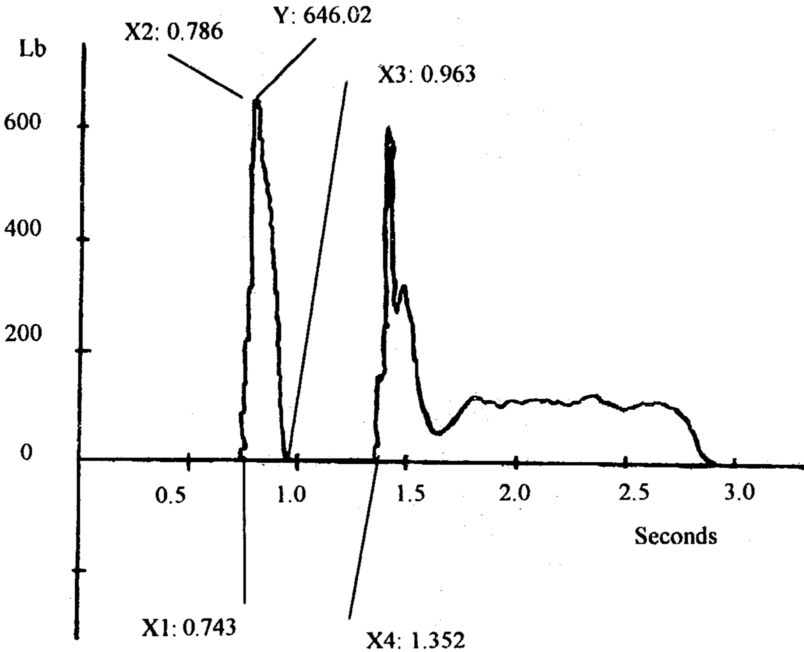
ABSOLUTE AND RELATIVE JUMP HEIGHTS OF EACH SUBJECT

ABSOLUTE AND RELATIVE JUMP HEIGHTS OF EACH SUBJECT

		ABSOLUTE VALUES (cm)		RELATIVE VALUES (%)	
SUBJECT	TRIAL	HARD	SOFT	HARD	SOFT
1	1	18.84	17.34	12.47	11.47
	2	18.08	16.88	11.96	11.17
	3	19.32	20.61	12.79	13.64
2	1	15.37	14.60	10.04	9.54
	2	14.60	17.24	9.54	11.27
	3	15.72	10.60	10.27	6.93
3	1	26.74	23.31	16.26	14.17
	2	23.74	21.12	14.43	12.84
	3	21.53	24.28	13.09	14.76
4	1	17.34	13.93	9.75	7.83
	2	15.45	13.60	8.69	7.65
	3	14.26	11.48	8.10	6.46
5	1	19.42	21.02	10.70	11.57
	2	19.72	22.36	10.86	12.31
	3	23.31	20.71	12.84	11.41
6	1	26.63	25.72	14.87	14.37
	2	23.42	24.28	13.08	13.56
	3	25.16	24.72	14.05	13.81
7	1	13.84	16.16	7.82	9.13
	2	10.60	13.60	5.99	7.68
	3	9.68	11.26	5.47	6.36
8	1	17.71	18.46	10.00	10.42
	2	17.24	16.52	9.74	9.33
	3	19.33	22.36	10.91	12.63
9	1	34.58	35.10	19.17	19.46
	2	34.06	32.40	18.89	17.95
	3	37.50	31.77	20.79	17.62
10	1	9.68	18.08	5.61	10.47
	2	17.71	18.46	10.25	10.69
	3	16.16	13.52	9.36	7.83
11	1	13.60	14.26	8.40	8.81
	2	11.26	13.52	6.95	8.35
	3	11.26	14.26	6.95	8.81
12	1	15.37	17.34	8.07	9.10
	2	17.24	19.42	9.05	10.20
	3	19.82	19.33	10.40	10.15
13	1	19.33	26.63	11.41	15.72
	2	25.16	28.61	14.85	16.88
	3	25.16	26.63	14.85	15.72
14	1	31.90	30.78	18.74	18.09
	2	32.90	31.90	19.33	18.74
	3	31.77	32.90	18.67	19.33
15	1	31.90	31.27	17.44	17.10
	2	32.40	23.74	17.72	12.98
	3	30.29	29.80	16.56	16.30
16	1	19.33	17.37	10.87	9.75
	2	18.94	16.88	10.65	9.49
	3	17.34	16.52	9.75	9.29

APPENDIX G

KINETIC GRAPH REPRESENTING HOW TEMPORAL VARIABLES WERE CALCULATED



Kinetic graph of vertical ground reaction forces during a depth jump.

<u>Legend to X and Y values</u>

X1: initial contact onto landing surface.

Y: peak vertical ground reaction force.

X2: time at which the vertical ground reaction force peaked.

X3: last point of contact with the landing surface prior to the vertical jump.

X4: reestablished contact with the landing surface during the descent of the vertical jump.