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The effects of varied rest interval lengths on depth jump performance

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THE EFFECTS OF VARIED REST INTERVAL LENGTHS ON DEPTH JUMP PERFORMANCE.

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ABSTRACT

THE EFFECTS OF VARIED REST INTERVAL LENGTHS ON DEPTH JUMP PERFORMANCE

by M. Michael Read

The purpose of this study was to measure the effects of varied rest interval lengths on the vertical jump heights and ground reaction forces during the execution of a depth jump from a predetermined optimal height. Each subject's optimal depth jump height was determined by executing depth jumps from 10-80 cm. After determining their optimal depth jump height, the subjects performed three sets of 10 depth jumps, each set with a different rest interval duration. The three rest intervals were 15, 30, and 60 seconds and were counterbalanced to each subject. Maximal vertical jump height and vertical ground reaction forces were calculated for each depth jump trial. Two-way analyses of variance revealed that rest interval length did not affect ($p > .05$) vertical jump height and vertical ground reaction forces. Therefore, this study demonstrated a 15 second rest interval was enough time for recovery.

This thesis is dedicated to my wife, Sam, and to my mom and dad.

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CHAPTER I

Introduction

This chapter will be organized into the following sections: background for the study, statement of the purpose, approach to the problem, statement of the null hypothesis, delimitations, assumptions, and definitions.

Background for the Study

Plyometrics are exercises that develop explosive power through the utilization of the stretch-shortening cycle (SSC). The stretch component of the SSC refers to the eccentric muscle action, while the shortening component refers to the concentric muscle action (Holcomb, Lander, Rutland, & Wilson, 1996). The SSC will only occur if there is an increased stiffness in the muscle tendon complex, which is adjusted by the neuromuscular system (Gollhofer, Strojnik, Rapp & Schweizer, 1992). Elastic energy is stored in the tendomuscular system during the eccentric action (Gollhofer & Kyrolainen, 1991). The time period between eccentric and concentric actions is known as the amortization phase (Chu, 1992). If the concentric action occurs immediately after the eccentric action, the muscles use the stored elastic energy (Komi, 1984) in combination with the normal voluntary tension to provide a more forceful contraction, which results in an increase in vertical jump height (Holcomb et al., 1996).

Depth jumps are plyometric exercises since they use the SSC to enhance performance. The depth jump involves dropping from a predetermined height, and upon landing the muscles are stretched or perform an eccentric action and store mechanical energy for the subsequent shortening or concentric action (Gollhofer & Kyrolainen, 1991). The downward, landing action is reversed into an upward, jumping action immediately after landing to ensure utilization of the stored elastic energy. A decreased amortization phase is a result of an increased speed of the eccentric action. The speed of eccentric action is affected by the dropping height (Bobbert, Huijing, & Van Ingen Schenau, 1987b). Therefore, it is important to determine an individual's optimal dropping height to ensure maximal utilization of the SSC to increase performance (Kyrolainen & Komi, 1995).

Depth jumps are used during strength and conditioning programs to improve acceleration and power in the vertical plane for a variety of different sports, such as basketball and volleyball (Chu, 1992). The utilization of depth jumps in training programs is beneficial to the power development of an athlete. However, the appropriate rest periods between sets and repetitions has never been studied. The rest period is usually stated as a period that allows athletes' recovery between sets (Young, Pryor, & Wilson, 1995). Making training recommendations without a definition of full recovery is difficult. Allerheiligen and Rogers (1995) recommended 15 to 30 seconds rest between repetitions and 3 to 4 minutes rest between sets. This recommendation was based on the author's own experience and intuition, not research.

Statement of the Purpose

The purpose of this study was to measure the effects of varied rest interval lengths on the vertical jump height and ground reaction forces during the execution of a depth jump from a predetermined optimal height.

Approach to the Problem

The participants of this study were 12 male volunteers, between 21 and 29 years of age, with a minimum of 1 year of weightlifting experience. The subjects performed three sets of 10 depth jumps from their optimal depth jump height. The optimal depth jump height was determined by having the subjects perform depth jumps from different heights between 10 and 80 cm (Kyrolainen & Komi, 1995). The height in which they performed the highest vertical jump was their optimal depth jump height. Each set of depth jumps was performed with a different rest interval length. The rest interval lengths were 15 (Sahlin & Ren, 1989), 30 (Stull & Clarke, 1971) and 60 seconds (Weir, Wagner & Housh, 1994). The order of the rest interval lengths were counterbalanced for each subject. Vertical jump height was measured by the Peak Performance Motion Measurement System and ground reaction forces were measured by a Kistler force platform.

Statement of the Null Hypothesis

There will be no difference between the three rest interval lengths (15, 30 and 60 seconds) on vertical jump height as measured by the rise in the height of the iliac crest during the depth jumps.

There will be no difference between the three rest interval lengths (15, 30 and 60 seconds) on ground reaction forces as measured in the Z direction during the depth jumps.

Delimitations of the Study

This study was delimited to 12 male students, between 21 and 29 years of age, from San Jose State University. All subjects had a minimum of 1 year of weightlifting experience.

Assumptions of the Study

For this research, all subjects performed to the best of their ability. The subjects all complied to the guidelines regarding no exercise within 24 hours of testing.

Definitions

The following definitions were used for this study:

Adenosine Triphosphate (ATP): A high energy phosphate stored within the muscle (McArdle, Katch & Katch,1991), which provides energy for muscular contraction and human movement (Stone & Conley, 1994).

Amortization Phase: "The delay between eccentric and concentric movements" (Holcomb et al., 1996, p. 89).

Countermovement Jump (CMJ): "A vertical jump performed with a preceding countermovement" (Komi & Bosco,1978, p.261).

Concentric Action: "The total tension developed in all the cross-bridges of a muscle is sufficient to overcome any resistance to shortening" (Hunter, 1994, p. 6).

Creatine Phosphate (CP): A high energy phosphate stored within the muscle (McArdle et al., 1991), which is required to rephosphorylate adenosine diphosphate into adenosine triphosphate (Sahlin & Ren, 1989; Stone & Conley, 1994).

Depth Jump: "Depth or drop jumping (DJ) involves jumping vertically immediately after landing from a fall or drop from a predetermined height" (Young, Pryor & Wilson, 1995, p. 232).

Eccentric Action: "The tension developed in the cross-bridges is less than the resistance, and the muscle lengthens despite contact between the myosin cross-bridge heads and the actin filaments" (Hunter, 1994, p. 7).

Phosphagen System: "The phosphagen system provides ATP primarily for short-term, high-intensity activities (e.g., weight training and sprinting) and is active at the start of all exercise regardless of intensity" (Stone & Conley, 1994, p. 69).

Plyometrics: "Drills or exercises aimed at linking sheer strength and speed of movement to produce an explosive-reactive type of movement" (Chu & Plummer, 1984, p. 30).

Power: "The time rate of doing work" (Harman, 1993, p. 18).

Strength: "The ability to exert maximal force" (Harman, 1993, p. 18).

Stretch-Shortening Cycle (SSC): "Pre-stretching a muscle prior to a concentric action can enhance force production during the subsequent contraction" (Hunter, 1994, p. 9).

Squat Jump (SJ): A vertical jump starting in a squatting position with a 90 degree bend in the knees (Komi & Bosco, 1978).

CHAPTER II

REVIEW OF LITERATURE

Introduction

This chapter will be organized into the following sections, effects of the stretch-shortening cycle on force production, importance of the amortization phase, depth jumps, and background of rest interval lengths.

Plyometric training has been used in strength and conditioning programs, to develop explosive power (Chu, 1992). Plyometric exercises include bounding, depth jumps, and medicine ball throws. A common ingredient to all plyometric exercises is that they utilize the stretch-shortening cycle, which increases the development of power. "A stretch-shorten cycle (SSC) can occur when an activated muscle is eccentrically stretched and immediately performs a concentric action" (La Chance, 1995, p. 16). Therefore, the stretch component of the SSC refers to the eccentric action, while the shortening component refers to the concentric action. "During the stretch of an activated muscle, mechanical energy is absorbed by the muscle, and this energy can be subsequently reutilized if the shortening of the muscle immediately follows the stretch" (Bosco, Tarkka, & Komi, 1982, p. 137). This energy is stored in the form of elastic energy and the reutilization of the elastic energy causes an elastic recoil, which enhances muscular performance during the concentric or shortening component of the SSC (Bosco, Tarkka, & Komi, 1982). The SSC allows the final concentric action to occur with a greater force or power output provided the concentric action immediately follows the eccentric action (Komi, 1984).

The time period between the eccentric action and the concentric action is known as the amortization phase (Chu, 1992; Holcomb et al., 1996) or coupling time (Bosco, Tihanyi, Komi, Fekete & Apor, 1982). The recoil of elastic energy depends upon the duration of the amortization phase (Chu, 1992) and the speed and length of contraction (Bosco, Ito, Komi, Luhtanen, Rahkila, Rusko & Viitasalo, 1982).

The depth jump is a plyometric exercise which increases force production through the utilization of the SSC (Bobbert, Huijing & Van Ingen Schenau, 1987a; Holcomb et al., 1996; Young et al., 1995). A depth jump is executed by dropping from a predetermined height and, upon ground contact, a vertical jump is executed.

The phosphagen system is the primary energy system supplying energy in the form of adenosine triphosphate (ATP) for activities lasting up to 6 seconds in duration (McArdle et al., 1991; Stone & Conley, 1994). Since depth jumps are high intensity short duration activities they utilize the phosphagen system as their primary energy supplier. Successful execution of a series of depth jumps is dependent upon the rest interval length between jumps.

Effects of the Stretch-Shortening Cycle on Force Production

A number of studies have measured the effects of the SSC on force development. These SSC exercises were compared to exercises that strictly utilize a concentric action (Asmussen & Bonde-Petersen, 1974; Bosco, Tarkka, & Komi, 1982; Komi & Bosco, 1978). Bosco, Tarkka, & Komi (1982) had subjects perform two different types of vertical jumps on a force platform. During the performance of both jumps, the subjects wore an orthopaedic cast covering their knees and hips, to ensure all movements were executed by the calf muscles through the ankle joint. The first jump was a squat jump (SJ). The subjects started with their heels flat on the force platform and were instructed to jump using maximal plantar flexion. The second jump was a counter-movement jump (CMJ). The subjects started by standing on their toes and prior to jumping, they performed dorsiflexion at the ankle. The dorsiflexion allowed the calf muscles to be stretched or eccentrically activated prior to the shortening phase or concentric action. The results of the study indicated the height of rise of the center of gravity and the average force production were both greater in the CMJ than in the SJ. The integrated electromyography (IEMG) activity of the calf muscles demonstrated similar patterns of activation during both jump conditions. These results supported the existence of the SSC. The CMJ utilized stored elastic energy from the eccentric action to improve performance (measured by rise of center of gravity and force production). The improvement in performance was attributed to the recoil of stored elastic energy, since the IEMG activity patterns were the same between both jump conditions.

Komi and Bosco (1978) used 57 male and female subjects to perform three different vertical jumps on a force platform: a squat jump (SJ), a counter-movement jump, and a drop jump (DJ). The SJ started in a squatting position with a 90 degree bend in the knees. The CMJ started from an erect standing position, with a preliminary eccentric action at the hip and knees prior to jumping. The DJ was performed by standing on boxes of different heights (20 - 100 cm), then dropping down to the force platform and subsequently jumping upwards. Both the CMJ and DJ used the SSC during the execution of the jump.

The results of the study indicated the SJ was significantly decreased in performance criteria, such as height of rise in the center of gravity and energy levels, in comparison to a CMJ and DJ for both male and female subjects. Female subjects had maximum height of rise of the center of gravity of 19.2 ± 3.6 cm for SJ, a 23.3 ± 3.5 cm rise during the CMJ, and a 27.3 ± 3.6 cm rise during the DJ. The male subjects had a 35.5 ± 5.1 cm rise during the SJ, a 40.3 ± 6.6 cm rise during the CMJ, and a 40.3 ± 6.9 cm rise during the DJ. There was no significant difference between the CMJ and DJ. The average optimal dropping height for the female subjects was 47.6 cm with 44.7 Joule (J) gain in positive energy during the concentric action, while the gain in positive energy during the CMJ was 23.0 J. The average optimal dropping height for males was 63 cm with a 35.5 J gain in positive energy during the concentric action, while the gain in positive energy during the CMJ was 35.5 J. These results demonstrated the existence of the SSC during a CMJ and DJ, resulting in better performances in comparison to the SJ.

A study by Asmussen and Bonde-Petersen (1974) also demonstrated the existence of the SSC. They used 19 subjects (14 males and 5 females) to perform vertical jumps from five different starting positions. The first two jumping conditions were a SJ and a CMJ, as defined previously by Komi and Bosco (1978). The other three jump conditions were a DJ from different starting heights: .233 m, .404 m, and .690 m. The results of this study indicated the height of the vertical jump was increased when performing either a CMJ or DJ as compared to a SJ. All three DJ conditions showed an increase in vertical jump as compared to the CMJ. The optimal DJ height (i.e., the DJ which had the highest vertical jump) occurred at .404 m. The average vertical jump height for the DJ from the height of .404 m was .408 ± .086 m, from the DJ height of .233 m was .396 ± .083 m, and from the DJ height of .690 m was .389 ± .086 m. The average vertical jump height during the CMJ was .386 ± .083 m, while the average vertical jump height during the SJ was .366 ± .071 m. During the CMJ, energy was generated, and either stored in the elastic components of the muscle or dissipated as heat. The majority of the energy was stored in the muscle during the stretching phase, thus allowing more energy to be available during the subsequent shortening phase of the SSC. There was a 23% increase in energy during the shortening phase as compared to the stretching phase, which resulted in an increase in vertical jump height in comparison to height achieved from the SJ. During a DJ, there was an increase in the load placed on the musculature, which caused an increase in the tightening (tension) and stretching of the elastic component of the muscle. This allowed more energy to be generated and consequently an increase in vertical jump height. However during the DJ, there was a decrease in vertical jump height following jumping from .690 m. This can be attributed to a larger amount of force during the stretching phase of a DJ from this height as compared to the other two heights. Therefore, the body's musculature was absorbing the impact of landing and the reflex inhibition decreased the following concentric action. This was an important study for three reasons. First, it demonstrated the existence of the SSC, which was evident from the higher vertical jump heights during the DJ and CMJ as compared to the SJ. Second, this study demonstrated the importance of determining the optimal depth jump height for each subject, since there was a performance decrement following the DJ at .690 m as compared to .233 m and .404 m. Finally, this study demonstrated that the DJ is a better SSC exercise for developing power and increasing vertical jump height than the CMJ.

The existence of the SSC was demonstrated in studies by Asmussen and Bonde-Petersen (1974), Bosco, Tarkka and Komi (1982), and Komi and Bosco (1978). All of the aforementioned studies compared the ability of different vertical jumps to generate force and achieve vertical jump height. The different vertical jumps included a SJ (i.e., concentric action only) and either a CMJ or a DJ (i.e., concentric action immediately followed the eccentric action). The CMJ and the DJ demonstrated improvements in jumping performance, attributed to the recoil of elastic energy.

Importance of the Amortization Phase

To effectively utilize elastic energy, the concentric action must be executed immediately after the eccentric action. The electromechanical delay between eccentric and concentric actions is known as the amortization phase (Chu, 1992; Holcomb et al., 1996), or coupling time (Bosco, Tihanyi, et al., 1982). As the amortization phase is increased, the time between eccentric and concentric actions is also increased, causing a decrease in force production. When the amortization phase is decreased, a corresponding increase in force production occurs (Chu, 1992). Not only is the length of the amortization phase important during the recoil of elastic energy, but the ability of the muscle to utilize elastic energy is also dependent upon the speed and length of contraction (Bosco, Ito, et al., 1982).

Fukashiro, Komi, Jarvinen, and Miyashita (1995) used one subject who performed three different vertical jumps on a force platform with an implanted transducer in his Achilles tendon to measure force. The vertical jumps included a SJ, a CMJ, and hopping. The results of the study indicated that hopping had the highest amount of force generated in the triceps surae complex, and the highest percentage of elastic energy stored in the Achilles tendon (34%). Based on this information it would seem reasonable to conclude that hopping had the highest rise of center of gravity. On the contrary, the CMJ had the highest rise in center of gravity of 40 cm. The SJ had a rise of 33 cm, while hopping had a rise of 7 cm. There are two possible explanations for these differences. First, the measurement of force only occurred in the triceps surae muscle complex. This would be beneficial to hopping, since the primary movements in hopping were plantar flexion and dorsiflexion, both controlled by the triceps surae muscle group. However, the SJ and the CMJ included hip extension/flexion and knee extension/flexion leading to a greater total force. The second possibility was the CMJ had the highest vertical velocity at take-off (2.80 m/s), while hopping had the slowest vertical velocity at take-off (1.17 m/s). This supports Bosco, Ito, et al. (1982), who stated the ability to utilize stored elastic energy, to increase performance, was dependent upon the speed of muscular contraction. The shorter the take-off time (i.e., faster the vertical velocity), the shorter the amortization phase and consequently, a better utilization of stored elastic energy (Fukashiro et al., 1995). Therefore, the CMJ had the highest rise in the center of gravity due to the fastest vertical velocity.

A study by Kyrolainen and Komi (1995) measured the mechanical efficiency (i.e., amount of work done as a proportion of energy expended) in 11 power trained athletes and 10 endurance trained athletes. An increase in mechanical efficiency corresponds with a decrease in the metabolic demands of the muscle, since the muscle will have a better utilization of elastic energy. The optimal depth jump height was determined for each subject. They performed a total of 60 muscle actions during a 3 minute period for three different DJ conditions: optimal DJ, optimal DJ + 40 cm, and optimal DJ - 40 cm. The results of the study indicated the power trained athletes generated more power than the endurance athletes. The power trained athletes' average angular velocity at the knee joint in the eccentric phase correlated negatively (r = -.77) with energy expenditure, while endurance athletes had a positive correlation (r = .21 to .57). As the power athletes increased knee velocity, they decreased their energy expenditure. Therefore, the mechanical efficiency increased with an increase in stretching velocity, which caused an increase in the recoil of stored elastic energy, which lead to an increase in force and power production. As Fukashiro et al. (1995) noted: the increase in stretching velocity caused a decrease in amortization phase and hence, an increase in power production. Therefore, it is extremely important to minimize the duration of the amortization phase to increase vertical jump performance.

Bosco, Ito, et al., (1982) exposed five subjects to five different jumping conditions: a CMJ with a small knee angle amplitude, a CMJ with a large knee angle amplitude, a CMJ with only body weight, a CMJ with an additional loading of 20 kg, and a SJ with a 1-second period between eccentric and concentric contractions. The results of the study indicated the CMJ with small knee angle amplitudes were characterized by an increased stretching speed, decreased amortization phase, and an increased force production. While, the CMJ with a large knee angle amplitude was associated with a decreased stretching (i.e., eccentric action) speed, increased amortization phase, and a decreased force production. The contribution of total positive work due to elastic energy accounted for 50% of total work in the small amplitude CMJ and 30% of total work in the large amplitude CMJ. Therefore to develop the same amount of force, less myoelectrical activity is required during the small amplitude CMJ. This study supported the importance of an increased stretching speed and a decreased amortization phase in order to optimize force development through the utilization of stored elastic energy. The authors suggested a rapid stretching of the muscle can modify the cross-bridges by turning the myosin heads against their natural position to a position of higher potential energy, which increased the stored energy in the muscle that can be recovered during the concentric work.

Bosco, Tihanyi, et al., (1982) examined the effect of fiber type on the utilization of elastic energy in 14 power trained athletes (10 male and four female subjects). The subjects performed both a SJ and CMJ with small and large knee angular displacements on a force platform. The results demonstrated the force developed at the end of the stretching phase had a significant relationship with fiber type during a jump with a small angular displacement, but not with a large angular displacement. During a CMJ with a small angular displacement, as the percentage of fast twitch muscle fibers increased, the force developed also increased. This positive relationship was due to the elastic components of the muscle. The recoil of elastic energy during the concentric action depends upon the amount stored during the eccentric action and the duration of the amortization phase. The small amplitude CMJ had a shorter and faster eccentric action with a shorter amortization phase, than the large amplitude CMJ. The longer amortization phase of the large amplitude CMJ caused the fast twitch fibers to detach and lose their elastic energy in the form of heat, which resulted in a decreased force production since primarily slow twitch fibers were used to sustain the contraction.

Thys, Faraggiana, and Margaria (1972) used six subjects and divided them into two groups: a rebound group in which extension occurred immediately after flexion during squatting and a no rebound group with a 1.5 sec interval occurring between extension and flexion of squatting. The results of the study indicated that the rebound group's force exerted on the platform (250 kg) during the extension or concentric phase was much greater than the no rebound group's force (150 kg) during the concentric phase. There was also an increase in the speed of lifting and the power developed during the rebound condition. This study demonstrated the importance of minimizing the time spent during the amortization phase to increase force and power production during the concentric muscle action. During the no rebound condition, a 1.5 sec delay was required between the eccentric and concentric actions, which allowed the muscles to relax and consequently the elastic energy was dissipated into heat and could not be reutilized during the concentric action.

The amortization phase was the period between the eccentric action and the concentric action. The ability to use stored elastic energy from the eccentric action during the concentric action was dependent upon the duration of the amortization phase (Bosco, Tihanyi, et al., 1982; Fukashiro et al., 1995; Kyrolainen & Komi, 1995; Thys et al., 1972), the knee angle amplitude and the speed of eccentric action (Bosco, Ito, et al., 1982; Bosco, Tihanyi, et al., 1982). A decreased amortization phase, a decreased knee angle amplitude, and an increased speed of eccentric action, all contribute to the enhanced force and power production via utilization of the SSC.

Depth Jumps

"Depth or drop jumping involves jumping vertically immediately after landing from a fall or drop from a predetermined height" (Young et al., 1995, p. 232). Depth jumping utilizes the SSC to improve jumping ability and athletic performance by developing the leg extensor muscles. During the depth jump, the first part of ground contact after dropping from the predetermined height stretches the muscles eccentrically. Elastic energy is stored during this impact phase of the ground contact in the tendomuscular system. The elastic energy is utilized in the subsequent concentric action to improve performance or to increase efficiency of contraction (Gollhofer & Kyrolainen, 1991). A number of studies (Bobbert et al., 1987a; Holcomb et al., 1996; Young et al., 1995) have demonstrated the effectiveness of depth jumps in their ability to develop power through the SSC.

Holcomb et al. (1996) used 11 subjects to evaluate three different depth jumps that isolated the three muscle groups in the lower body which are required for jumping. The three depth jumps were compared to a CMJ. The depth jumps included ankle depth jumps (ADJ), knee depth jumps (KDJ) and hip depth jumps (HDJ). The depth jumps were performed from a height of 50 cm. The results of the study demonstrated the depth jumps were significantly greater than the CMJ for increased power production in the isolated joints. The modified depth jumps enhanced the contribution of the muscles required to extend the ankle, knee, and hip as compared to the CMJ. However, isolating specific muscle groups during depth jumps would not be beneficial for training, since it does not teach an individual to jump in a sequential fashion. However, it does demonstrate the effectiveness of depth jumps for power production in comparison to CMJ.

A study by Young et al. (1995) used 17 males to compare CMJ with DJ using three different instructions. The three DJ instructions included performing a depth jump for maximal height (DJ-H), performing a depth jump for maximal height and minimal contact period (DJ-H/t), and to perform a depth jump for minimal contact period (DJ-t). The DJ heights were 30, 45, and 60 cm performed in that order with complete recovery allowed. All jumps were executed with the subject's hands on his hips and he performed jumps until a decreased performance occurred. The results of the study indicated the highest rise of center of gravity occurred during the CMJ and DJ-H from 30, 45, and 60 cm, respectively. The mean $\pm$ SD rise in center of gravity was 41.9 $\pm$ 8.3 cm during the CMJ and 40.2 $\pm$ 7.7cm, 39.8 $\pm$ 7.9 cm, and 39.6 $\pm$ 7.8 cm during the DJ-H from 30, 45, and 60 cm, respectively. The DJ-H produced the longest contact times of 409 $\pm$ 78 ms, 415 $\pm$ 71 ms, and 421 $\pm$ 79 ms during the DJ-H from 30, 45, and 60 cm, respectively. When the only objective was jumping for height, the subjects used a low squat position and a long takeoff period during the DJ-H. The DJ-H/t had contact times of 177 $\pm$ 25 ms, 180 $\pm$ 31 ms, and 186 $\pm$

33 ms for depth jumps from 30, 45, and 60 cm, respectively, which were 56-57% faster than the contact times from the DJ-H. It does not seem possible that a true SSC existed with the DJ-H due to the extremely long contact times and the long amortization phase. When the subjects performed the DJ-t, the contact times were 141 $\pm$ 13 ms, 143 $\pm$ 17 ms, and 154 $\pm$ ms, for depth jumps from 30, 45, and 60 cm, respectively, which was significantly faster than the contact times during the DJ-H. Also, during the DJ-t the height jumped was 12.5 $\pm$ 6.5 cm, 10.3 $\pm$ 6.1 cm, and 9.3 $\pm$ 6.2 cm for DJ from 30, 45, and 60 cm, respectively, which were significantly lower than depth jump heights from the DJ-H and DJ-H/t. The DJ-H/t had vertical jumps of 33.1 $\pm$ 5.0 cm, 32.3 $\pm$ 5.6 cm, and 31.3 $\pm$ 5.8 cm for DJ from 30, 45, and 60 cm, respectively. Therefore, the DJ-H/t appears to be the most effective technique for executing a depth jump, since it developed power through fast and forceful contractions. This study also demonstrated the importance of determining the optimal depth jump height, since the jump height decreased and the contact time increased as the depth jump height increased. Even though the subjects experienced greater stretch loads with the increased depth jump height, they were unable to utilize these forces, as noted by the decreased jumping performance.

A study by Bobbert et al. (1987a) measured the effects of jumping technique on vertical jump performance. They used three different types of jumps: a CMJ, a countermovement drop jump (CDJ), and a bounce drop jump (BDJ). The BDJ required the subjects to reverse their downward velocity into an upward one as soon as possible after landing, and the CDJ required the subjects to make a larger downward movement upon landing prior to jumping.

The results of the study indicated the BDJ created a larger power output than CMJ and CDJ, with equal EMG activity levels. The BDJ also attained the shortest time interval between the peak velocity of eccentric action and the start of concentric action. This study demonstrated the importance of using depth jumps instead of CMJ to develop power and increase vertical jumping performance, and depth jumps with faster stretching phases and shorter amortization phase (BDJ) utilized stored elastic energy more effectively than depths jumps with a slower stretching phase and a longer amortization phase (CDJ).

Depth jumps have been demonstrated to be a more effective plyometric exercise than countermovement jumps for utilizing the stretch-shortening cycle to increase power output and force production, leading to an increase in vertical jumping performance (Bobbert et al., 1987a; Holcomb et al.,1996; Young et al., 1995;). However, simply performing depth jumps from any height will not be an effective way to use depth jumps. Therefore, determining an individual's optimal depth jump height is important. Optimal depth jump height is the height in which subjects achieve their best results for the height of rise of their center of gravity (Kyrolainen & Komi, 1995). Executing depth jumps above the optimal height will result in a decrease in vertical jumping performance, due to an inability to effectively use stored elastic energy. As the depth jump height is increased above optimal height, a corresponding increase in the stretch load occurred which caused an increase in eccentric work and a decrease in concentric work (Bobbert et al., 1987b; Gollhofer, Strojnik, Rapp, & Schweizer, 1992). The increased stretch load caused a deceleration of the body mass at the instant of touch down, which caused part of the energy to be absorbed by the bone-ligament system instead of being stored by the tendomuscular system (Gollhofer et al., 1992). Additional loading on the tendomuscular system caused by an increase in depth jump height above optimal height, increased the eccentric phase and amortization phase which decreased the chance of utilizing potential elastic energy during the subsequent concentric phase (Bosco, Viitasalo, Komi, & Luhtanen, 1982). The increased duration of the eccentric action can be interpreted as a reflex inhibition (Asmussen & Bonde-Petersen, 1974) or protective mechanism of the neuromuscular system to prevent intolerable stresses in the tendomuscular system (Gollhofer & Kyrolainen, 1991).

Performing depth jumps from higher than optimal depth jump height will decrease vertical jump height and performing depth jumps below optimal depth jump height will decrease vertical jump height. An increase in vertical jump height attributed to the utilization of the SSC is due to the elastic phenomenon. When an active muscle is stretched, it increases its tension and stores potential elastic energy (Komi, 1984). The storage of elastic energy is directly related to the stiffness or tension of the muscle. Increased muscle stiffness is caused by a combination of high motor unit activation and a simultaneous increase in the force of the eccentric action (Bosco, Viitasalo, Komi, & Luhtanen, 1982). Executing depth jumps with unloading conditions or decreased jump height below optimal height will not provide the tendomuscular system adequate stiffness; therefore, the ability to jump reactively is decreased (Gollhofer & Kyrolainen, 1991). A decreased stretch load caused a decrease in preactivation of the neuromuscular system and hence, no recoil of elastic energy can be expected (Gollhofer & Kyrolainen, 1991).

Depth jumps have been demonstrated to be a more effective way to increase power output, force production, and jumping performance than other vertical jumping conditions such as CMJ (Bobbert et al., 1987b; Holcomb et al., 1996; Young et al., 1995). Determining an individual's optimal depth jump height is important (Kyrolainen & Komi, 1995; Young et al., 1995). An increase in height above optimal depth jumping height will decrease performance due to increased stretch load and eccentric work with corresponding decreased concentric work, resulting in a decreased ability to use stored elastic energy (Bobbert et al., 1987b; Gollhofer et al., 1992). A decrease in height below optimal depth jumping will decrease performance due to a decreased stiffness in the tendomuscular system and a decreased preactivation of the neuromuscular system (Gollhofer & Kyrolainen, 1991).

Background of Rest Interval Lengths

Depth jumps are an exercise of short duration and high intensity; therefore, the primary energy system is the phosphagen system. The phosphagen system supplies energy for high intensity exercises lasting up to approximately 10 seconds in the form of adenosine triphosphate (ATP) and creatine phosphate (CP) (McArdle et al., 1991; Stone & Conley, 1994). Energy is supplied through the breakdown of ATP by myosin ATPase into adenosine diphosphate (ADP) and inorganic phosphate. The increased ADP concentration initiates the formation of ATP by combining with CP (Stone & Conley, 1994). Five mmol of ATP and 15 mmol of CP are stored within each kilogram of muscle (McArdle et al., 1991).

The intensity and duration of exercise is a direct cause of muscular fatigue (Hannie, Hunter, Kekes-Szabo, Nicholson & Harrison, 1995). During intense exercise there is a rapid decrease in the ability to generate force due to an accumulation of lactic acid and a depletion of CP (Sahlin & Ren, 1989). A possible mechanism for the decrease in force is the capacity to regenerate ATP, if the ATP supply becomes insufficient to meet the demands of the exercise (Sahlin & Ren, 1989). The ability to increase the rate of recovery may increase the potential workload and therefore increase the training adaptation (Hannie et al., 1995). The restoration of the ATP-generating capacity is dependent upon the rate at which CP was resynthesized, since the breakdown of CP is required to rephosphorylate ADP into ATP (Sahlin & Ren, 1989; Stone & Conley, 1994). The recovery of ATP requires approximately 3-5 minutes while CP recovery occurs after approximately 8 minutes (Robinson et al., 1995).

Hannie et al. (1995) measured the effects of active recovery on the number of sets and repetitions performed and the force exerted during the bench press exercise. The 15 subjects were randomly assigned to either the active recovery group (i.e., 1 minute of cycling at 45% of maximal oxygen uptake rate and 1 minute of sitting) or the inactive recovery group (i.e., sitting for 2 minutes). All subjects performed bench press to failure at 65% of their 1-RM (i.e., maximum amount of weight lifted once). The results of the study indicated the active recovery group performed significantly more sets and repetitions with no difference in force production than the inactive recovery group. Even though the inactive recovery group's total volume (i.e., sets X repetitions) of work was not as high as the active recovery group's total volume, the force production was not significantly different between the two groups. Therefore inactive recovery would be appropriate for execution of a depth jump since a depth jump is a highly intense, single repetition movement with a tremendous production of force.

Sahlin and Ren (1989) measured the effect of force production capabilities during recovery from a previous fatiguing isometric contraction in relation to the metabolic changes within the muscle. Their results indicated the force production capabilities were rapidly restored during the recovery period and by 15 seconds it was 79.7 ± 2.3% of maximal voluntary contraction (MVC). After 2 minutes of recovery following a sustained isometric contraction at 66% of MVC, maximal isometric force production was not significantly different than before the fatiguing contraction. The initial value of CP was 87.3 ± 1.9 mmol/kg dry weight. After the fatiguing isometric contraction the MVC's CP value was 9.4 ± 1.1 mmol/kg dry wt., or 11% of the initial value. Following 2 minutes of recovery, the CP value was 57.8 ± 3.8 mmol/kg dry weight, or a 67% restoration of CP had occurred. After 4 minutes of recovery the CP concentration was 74.3 ± 3.5 mmol/kg dry weight, or 84% of the CP was restored. This study demonstrated that force production will remain equal following fatigue, even though CP was not completely restored. It also showed a single maximum contraction was not long enough to completely abolish CP stores, since equal production of force occurred with 33% less CP present in the muscle. The ability to execute depth jumps with maximal performance during each jump should not be affected by CP depletion, and an extensive rest period of 2 minutes or more should not be required. Finally, this study demonstrated maximal isometric force production capabilities 15 seconds after the fatiguing contraction were 80% of the maximal force before fatigue. Since the depth jumps will not be performed after a fatiguing exercise, a 15 second rest interval length may be a long enough recovery period to optimize depth jump performance.

Stull and Clarke's (1971) results were supported by Sahlin and Ren (1989). Stull and Clarke's (1971) results demonstrated recovery from muscular fatigue was dependent upon the previous exercise period, including the type of muscular contraction, the rest interval length, and the duration of activity. After 1 minute of maximal isometric contraction, the strength level decreased from an initial mean of 54.47 kg to 26.51 kg, a decrement of 27.96 kg or a loss of 51% of strength. After 3 minutes of maximal isotonic contractions the strength level decreased from an initial mean of 55.12 kg to 31.82 kg, a decrement of 23.30 kg or a loss of 42% of strength. Recovery following isotonic strength tests occurred faster than isometric strength tests. Strength levels after 10 seconds were 10.15 kg or regained by 36% for isometric muscle contraction and 13.15 kg or regained by 56% for isotonic muscle contraction. After 35 seconds rest, strength levels were 49% and 84% of initial values, following isometric and isotonic muscle contractions, respectively. Complete recovery occurred at 115 seconds following isotonic muscle contractions and 235 seconds for isometric muscle contractions. At 170 seconds, a 5% increase above initial strength levels occurred during the isotonic exercise. As indicated by Sahlin and Ren (1989), minimal recovery during a depth jump without prior fatigue will be required to optimize performance.

A study by Harris et al. (1976) demonstrated CP concentration had a drastic decrease following exercise and ATP concentration had a minimal decrease following exercise. The type of exercise and the duration of the exercise affects CP concentration. One group performed dynamic exercise to exhaustion on a bicycle ergometer, which lasted approximately 6 minutes. The other group performed isometric contractions at 66% of maximal voluntary contraction to exhaustion. The CP concentration was 16% of the resting value following dynamic exercise and 15% of the resting value following isometric exercise. After 2 and 4 minutes of recovery, the CP concentration deficit were restored to 84% and 89% of initial values, following dynamic exercise, and 68% and 72% of initial values, following isometric exercise. These exercise tests were tests to exhaustion lasting 2 - 6 minutes. Approximately 85% of the CP stores were depleted, with 68% and 84% restoration of CP following 2 minutes recovery for the isometric and dynamic exercise conditions, respectively. Therefore, a depth jump lasting approximately 1 second will not deplete CP stores to the same extent and will not require the same recovery length following each depth jump.

Studies by Sewall and Lander (1991) and Weir et al. (1994) may be more appropriate studies for applying the results of recovery to a depth jump. These studies measured the effects of rest interval length on the execution of repeated 1-RM attempts in the bench press (Weir et al., 1994) and the bench press and squat (Sewall & Lander, 1991). Sewall and Lander (1991) discovered no significant difference existed between 1-RM attempts with a 2, 6 or 24 hour rest period. This study demonstrated the importance of recovery during a weightlifting competition, but does not demonstrate the practical significance for recovery during a workout. Weir et al. (1994) used recovery periods of 1, 3, 5 and 10 minutes between 1-RM attempts. The results of their study indicated no significant difference between the four rest interval lengths. Weir et al. (1994) concluded the dominant energy system was the phosphagen system and since the subjects only performed a single repetition per set, little intramuscular fatigue occurred and a long rest period was not required.

The phosphagen system was the primary energy system supplying energy for depth jumps, since depth jumps are a high intensity and short duration exercise. Recovery following a depth jump is dependent upon the ability to regenerate ATP via CP resynthesis (Sahlin & Ren, 1989; Stone & Conley, 1994). Inactive recovery was demonstrated as an appropriate method for the restoration of force production following fatiguing exercise (Hannie et al., 1995) and therefore will be useful for recovery from depth jumps. Rest intervals as short as 10 (Stull & Clarke, 1971) to 15 seconds (Sahlin & Ren, 1989) and as long as 1 minute (Weir et al., 1994) following depth jumps will be appropriate time periods for recovery.

Summary

Depth jumps are plyometric exercises which utilize the SSC to develop force and power. Utilization of the SSC is dependent upon a number of factors, such as a decreased length of the amortization phase (Bosco, Tihanyi, et al., 1982; Fukashiro et al., 1995; Kyrolainen & Komi, 1995; Thys et al., 1972), an increased speed of eccentric action, a small knee angular displacement (Bosco, Ito, et al., 1982; Bosco, Tihanyi, et al., 1982), and the optimal height of the depth jump (Kyrolainen & Komi, 1995).

The ability to execute a series of depth jumps is dependent upon the rest interval duration in order to allow for restoration of CP (Sahlin & Ren, 1989; Stone & Conley, 1994). Based on a study by Weir et al. (1994), who discovered successful performance of subsequent maximum bench presses occurred within a 1 minute rest period, a maximal time period for depth jump recovery should be 1 minute. A minimal recovery of 10 (Stull & Clarke, 1971) to 15 seconds (Sahlin & Ren, 1989) would be required, since these two studies found an increase in force production following fatiguing contractions using these rest interval lengths.

CHAPTER III

METHODOLOGY

Introduction

This chapter contains information about the subjects, experimental design, measurements and methods, and statistical analyses.

Subjects

Twelve male volunteer subjects, between 21 and 29 years of age, were used in this study. The subjects were currently on a weight lifting program with a minimum of 1 year of weight lifting experience, as determined by the health screening questionnaire (Appendix A). The subjects were recruited for this study from San Jose State University. The subjects completed a health screening questionnaire (Appendix A) and signed a human subjects informed consent form (Appendix B) before participating in this study. Only healthy subjects without current medical and/or health problems were used in this study.

Experimental Design

The subjects were required to report to the exercise physiology laboratory on four different occasions: (1) to determine their optimal depth jump height, (2) to perform 10 depth jumps from the optimal height with a 15 second rest period, (3) to perform 10 depth jumps from the optimal height with a 30 second rest period and, (4) to perform 10 depth jumps from the optimal height with a 60 second rest period. The order of the rest interval lengths used in testing was counterbalanced for each subject. Prior to performing the depth jumps, the subjects performed a general warm-up (Appendix C). The subjects were then given a verbal explanation on how to perform a depth jump

(Appendix D) with a visual demonstration. They received three practice depth jumps off a 20 centimeter (cm) box with 3 minutes recovery between the two depth jumps (Bobbert et al., 1987a). Vertical jump heights and ground reaction forces were measured during the 10 depth jump trials. Each testing day was followed with at least 24 hours of rest, before the next testing session, and the subjects were instructed not to exercise within 24 hours of the testing session.

Measurements and Methods

Body Weight and Size

Height and leg length were measured with a wall scale utilizing a Broca (TM) plane. Height and leg length were expressed in cm. Height was measured from the apex of the skull to the floor and leg length was measured from the greater trochanter to the floor. Leg length was averaged from the measurements of both right and left legs. Body weight was measured in kilograms (kg) on a platform scale and was converted to Newtons (N), by multiplying by 9.81.

Optimal Depth Jump Height

The subjects were tested using the Peak Performance Motion Measurement System to measure the height of rise of the iliac crest. Each subject executed a series of depth jumps from different heights. The heights ranged from 10 - 80 cm, increasing by 10 cm for each jump. The subjects received a 3 minute rest period between each depth jump. The height in which they achieved their highest rise in their iliac crest was their optimal depth jump height (Kyrolainen & Komi, 1995).

Vertical Jump Height

The Peak Performance Motion Measurement System was used to measure the vertical jump height. Included within the Peak Performance Motion Measurement System were the following: HIQ personal computer, peak 5.0 software, Panasonic AG 6300 VCR, Panasonic CT 1400 MG color video monitor, and the Panasonic AG 450 video camera which tapes at 60 fields per second. The video camera was 1.3 meters high and was 5 meters from the force platform. It was positioned perpendicular to the sagital plane. The iliac crest of each subject was marked with tape and digitized, and through video analysis the height rise of the iliac crest was determined. The difference between each subjects iliac crest while standing and the height of their iliac crest at peak flight was determined as their vertical jump height. All subjects were instructed to wear black shorts (or they were provided) to mark the iliac crest with white tape. The rise of the iliac crest was measured in cm.

Ground Reaction Forces

A Kistler force platform, model 5004 dual model amplifier, was used to measure the ground reaction forces during the depth jump. The ampliflier was set at 1-11, which collected 600 samples of force/second, for 3 seconds before and after jumping. The Kistler force platform was manually triggered and interfaced to the Peak Performance Motion Measurement System. The ground reaction forces were measured in N in the Z direction during take off.

Rest Interval Lengths

The rest interval lengths were counterbalanced for each subject. Since, there was a total of 12 subjects with three rest interval lengths, a total of six combinations occurred for the rest interval order, with two subjects in each group. The rest interval orders were as follows: 15, 30, 60; 15, 60, 30; 30, 15, 60; 30, 60, 15; 60, 30, 15; and 60, 15, 30. All subjects were tested using each rest interval length: 15, 30, and 60 seconds. The rest period was measured using a Timex quartz stopwatch and the rest started immediately after complete execution of the depth jump. All results were recorded on the results score sheet (Appendix E).

Statistical Analysis

All subjects were counterbalanced to their rest interval lengths to control for a training effect. Descriptive statistics were calculated and reported for the vertical jump heights, ground reaction forces, optimal jump height, age, height, body weight, and leg length. Two-way analyses of variance were used to determine if differences exist in the vertical jump heights between the three rest interval lengths and to determine if differences exist in the ground reaction forces between the three rest interval lengths. One-way analyses of variance with Tukey post hoc tests were used as follow-up procedures on the significant main effect found in the two-way analyses of variance. The alpha level was set at .05 for this study.

Summary

Twelve male students, between 21 and 29 years of age, were the subjects used for this research. Prior to testing, all subjects' optimal depth jump heights were determined by having each subject execute a series of depth jumps from different heights. The height in which they had their highest rise in the iliac crest was their optimal depth jump height. The subjects were tested on the effects of varying rest interval lengths on the performance of a depth jump from optimal depth jump height. All subjects were tested three times using a different rest interval length. The rest interval lengths were counterbalanced for each subject for his respective testing days. The three different rest interval lengths included 15, 30, and 60 seconds. The height of rise of the iliac crest was measured using the Peak Performance Motion Measurement System. Two-way analyses of variance were used to determine if differences exist in the vertical jump heights and the ground reaction forces between the three rest interval lengths. One-way analysis of variance with Tukey post hoc tests were used as follow-up procedures on the significant main effect found in the two-way analyses of variance.

CHAPTER IV

RESULTS

Introduction

This chapter is organized into the following sections: analysis of data and a summary.

Analysis of Data

Twelve healthy male subjects, between 21-29 years of age, with at least one year of weightlifting experience were tested in the study. Table 1 summarizes the physical characteristics of the subjects. The range of the subjects optimal depth jump height was 30 - 80 cm, with a mean height of 61.67 cm.

Table 2 summarizes the vertical jump heights achieved from optimal depth jump height for all 12 of the subjects. The mean vertical jump heights were recorded for each of the 10 jump trials for the 15, 30, and 60 second rest interval lengths. Two-way analysis of variance demonstrated non-significant differences for the effects of rest interval on vertical jump height, non-significant differences for the interaction effects of rest interval length across the 10 jump trials, and significant differences for the effects of the 10 jump trials on vertical jump height. One-way analyses of variance demonstrated statistically significant differences across the 10 jump trials during the 30 second rest interval length, and no sigificant differences for either the 15 second rest interval length, or the 60 second rest interval length. Tukey post hoc analyses demonstrated the statistically significant difference during the 30 second rest

Table 1

Physical characteristics of the subjects

	Height (cm)	Weight (N)	Leg Length (cm)
M	174.24	805.70	100.43
SD	6.28	101.63	6.40
Range	161.0 - 182.1	616.07 - 965.30	83.2 - 107.3

	Age (years)	Optimal Depth Jump (cm)
M	25.08	61.67
SD	2.43	16.42
Range	21 - 29	30 - 80

N = 12

Table 2

Vertical jump heights from optimal depth jump height at each rest interval

		Jump Trial									
		1	2	3	4	5	6	7	8	9	10
Rest	15										
	M	40.9	40.2	40.2	40.1	40.7	40.0	41.4	41.0	41.0	42.5
	SD	6.2	6.7	5.3	5.9	4.4	5.8	4.9	5.5	5.8	5.0
Rest	30										
	M	41.2	39.7	39.2	39.2	41.1	39.7	41.2	40.8	40.4	41.5
	SD	6.0	6.4	4.9	5.6	4.9	6.3	6.4	5.9	5.9	5.7
Rest	60										
	M	39.5	39.5	39.6	40.3	40.1	40.6	40.5	38.6	39.3	39.6
	SD	6.3	4.9	5.2	4.7	5.1	4.3	4.8	5.2	5.6	5.5

Note. Values are reported in centimetres and represent the $M \pm SD$ for 12 subjects. Two-way analysis of variance demonstrated non-significant differences for the effects of rest interval length on vertical jump height, $F(2,22) = .244$ $p > .05$, demonstrated non-significant differences for the interaction effects of rest interval length across 10 jumps, $F(18,198) = .090$ $p > .05$, and significant differences of the 10 jump trials on vertical jump height, $F(9,99) = .023$ $p < .05$. One-way analyses of variance demonstrated statistically significant differences across the 10 jump trials during the 30 second rest interval length, $F(9,99) = .007$ $p < .05$, and no sigificant differences for either the 15 second rest interval length, $F(9,99) = .217$ $p > .05$, or the 60 second rest interval length, $F(9,99) = .184$ $p > .05$. Tukey post hoc analyses demonstrated the statistically significant difference during the 30 second rest interval length occurred between jump trial number 3 and number 10, and between number 4 and number 10. The mean difference between the jump trials were greater than the Tukey post hoc critical difference needed for statistical significance at $p < .05$.

interval length occurred between jump trial number 3 and number 10, and between number 4 and number 10, since the mean difference between the jump trials were greater than the Tukey post hoc critical difference of 2.128.

The vertical ground reaction forces from the optimal depth jump height for six subjects are summarized in Table 3. The mean vertical ground reaction forces were recorded for each of the 10 jump trials for the 15, 30, and 60 second rest interval lengths. Two-way analysis of variance demonstrated non-significant differences, for the effects of rest interval length on vertical ground reaction forces, for the effects of 10 jump trials on vertical ground reaction forces, and for the interaction effects of rest interval length across 10 jump trials.

Summary

Statistically significant differences did not exist when the main effects of rest interval length on vertical jump heights was measured or when the interaction effects of rest interval length across the 10 jump trials was measured. Statistically significant differences did exist when the main effects of 10 jump trials on the vertical jump heights was measured. This statistically significant difference occurred during the 30 second rest interval length between jump trials number 3 and 10, and between jump trials number 4 and 10. Statistically significant differences did not exist on vertical ground reaction forces, when the main effects of rest interval length, the 10 jump trials, and the interaction effects of rest interval length across the 10 jump trials was measured.

Table 3

Vertical ground reaction forces from optimal depth jump at each rest interval

	Rest Interval Length		
	15 second rest	30 second rest	60 second rest
Jump (n = 6)			
1	7745.04 ± 1021.64	7178.59 ± 1012.50	7194.77 ± 974.75
2	7784.66 ± 844.74	7920.65 ± 1135.23	7699.00 ± 1274.24
3	7616.55 ± 792.25	7964.55 ± 763.77	7694.71 ± 1205.92
4	7549.09 ± 738.88	7875.68 ± 1222.76	7161.50 ± 1483.60
5	7687.22 ± 774.63	7741.83 ± 716.94	7998.82 ± 1284.29
6	7112.13 ± 811.85	7639.03 ± 533.39	7703.28 ± 1505.88
7	7754.68 ± 927.39	7888.48 ± 325.40	7861.76 ± 1195.87
8	7544.33 ± 845.61	7890.67 ± 848.00	7866.04 ± 1227.86
9	7639.03 ± 1319.64	7977.40 ± 1449.63	7605.84 ± 1113.37
10	7605.84 ± 1116.63	7933.50 ± 1626.28	7370.26 ± 1417.46

Note. Values are $M \pm SD$ reported in N. Two-way analysis of variance demonstrated non-significant differences, for the effects of rest interval length on vertical ground reaction forces, $F(2,10) = .728$ $p > .05$, for the effects of 10 jump trials on vertical ground reaction forces, $F(9,45) = .754$ $p > .05$, and for the interaction effects of rest interval length across the 10 jump trials, $F(18,90) = .622$ $p > .05$.

CHAPTER V

DISCUSSION

Introduction

This chapter is organized into the following sections: discussion of findings, summary, conclusions, weaknesses, recommendations for future research, and practical applications.

Discussion of Findings

The purpose of this study was to measure the effects of varied rest interval lengths on the vertical jump heights and ground reaction forces during the execution of depth jumps from a predetermined optimal height. After the data were gathered and analyzed for the 12 subjects, the only variable which demonstrated statistically significant differences was the effects of the number of jumps on vertical jump height.

Two-way analysis of variance which measured the effects of rest interval length and the interactive effects of rest interval length across the 10 jump trials on vertical jump heights demonstrated the rest interval did not cause statistically significant differences. A possible explanation of why the rest interval length did not affect vertical jump heights was the intensity and duration of the activity. According to Hannie et al. (1995), the intensity and duration of an exercise was a direct cause of muscular fatigue. Harris et al. (1976) demonstrated that maximal exercise tests to exhaustion lasting 2 - 6 minutes caused an 84% decrease in CP concentration following dynamic exercise and an 85% decrease following isometric exercise. A single, maximal, depth jump lasts less than one second and therefore does not completely deplete the phosphagen stores. Even when the phosphagen stores are completely depleted it can take approximately 3-5 minutes to replenish ATP, and complete CP restoration occurring after approximately 8 minutes (Robinson et al., 1995). Since a depth jump does not deplete the phosphagen stores, full recovery during the present study was not required for the regeneration of ATP or CP.

The exact rest interval length of 15, 30 or 60 seconds did not significantly affect vertical jump heights. Sahlin and Ren (1989) demonstrated that maximal isometric force 15 seconds after fatiguing contractions, was 80% of the maximal force prior to the contractions. Strength levels following isotonic contractions were 84% of initial strength values after 35 seconds of rest (Stull & Clarke, 1971). A 60 second rest interval length was used following maximum attempts in the bench press and the results demonstrated that there was no significant difference between trials (Weir et al., 1994). The aforementioned studies (Sahlin & Ren, 1989; Stull & Clarke, 1971; Weir et al., 1994) support the results of the present study, since the three rest interval lengths did not significantly affect force production and vertical jump capabilities. Even though Sahlin and Ren (1989) and Stull and Clarke (1971) performed fatiguing exercises prior to the strength tests, their studies still demonstrated a recovery of strength following the same rest interval lengths used in the present study. The experimental design of Weir et al. (1994) was similar to the present study since the 1-RM in the bench press was not preceded by fatiguing contractions. Therefore, neither the present study or Weir et al. (1994) reported significant differences following a 60 second rest interval length.

The two-way analysis of variance demonstrated the number of jumps caused a statistically significant difference for vertical jump heights. Since a significant difference existed in vertical jump heights across the 10 jump trials, one-way analyses of variance were required to determine which rest interval lengths had the significant difference. One-way analyses of variance demonstrated a statistically significant difference occurred during the 30 second rest interval length, but not during either the 15 or 60 second rest interval lengths. Since the one-way analyses of variance indicated a significant difference in the 30 second rest interval length, Tukey post hoc analyses were required to determine between which jump trials the statistically significant difference existed. Tukey post hoc analyses indicated a statistically significant difference existed between jump trials number 3 and number 10, and between jump trials number 4 and number 10. The differences between jump trials 3 (39.166 cm) and 10 (41.477 cm) and between jump trials 4 (39.170 cm) and 10 (41.477 cm) was greater than the Tukey post hoc critical difference of 2.128 cm. The difference between trial 3 and 10 was -2.311 cm and between 4 and 10 was -2.307 cm. The negative number demonstrated the vertical jump height improved from trials three and four to trial 10, therefore fatigue can be eliminated as a possible explanation for the significant differences. The rest interval lengths were counterbalanced and the same warm-up procedures were used for each rest interval length, therefore rest interval order and warm-up can be eliminated as possible explanations. There was no physiological explanation for this statistically significant difference; therefore it has been attributed to a chance occurrence. With the alpha level at .05, there was a 5% chance that statistically significant differences would occur because of a chance occurence, not the treatment effects. Other possible explanations for the significant differences were experimenter error and motivation of the subjects. The experimenter error may have occurred during digitizing. If the digitizing was off even a pixel on the computer monitor, that would cause a difference of millimeters after it was adjusted with the scaling rod.

Two-way analysis of variance which measured the effects of rest interval length, the effects of the number of jumps, and the interactive effects of rest interval length across the 10 jump trials on vertical ground reaction forces demonstrated that rest interval length did not cause statistically significant differences. A possible explanation for the non-significant differences was only six complete data sets were collected for the vertical ground reaction forces. The six incomplete data sets did have the majority of the forces collected, however even if one force was missing, the two-way analysis of variance would not accept any of the forces for that subject. The reason only six complete sets were collected was an experimenter error in collecting the data. The Kistler force plate had to be automatically triggered by the researcher prior to the subject hitting the force plate. It was assumed that the force plate was not triggered in time for the missing force values. This was not determined until after the data was completely collected and analysis had begun.

<u>Summary</u>

The non-significant results of the effect of rest interval lengths on vertical jump heights, and the interactive effects of rest interval length across 10 jump trials on vertical jump heights can be attributed to the intensity and duration of the depth jump. The depth jump does not completely deplete phosphagen stores and therefore depth jump heights and vertical ground reaction forces were not different between 15, 30, and 60 second rest periods. Through utilization of two-way analysis of variance, one-way analyses of variance and the Tukey post hoc analyses, a statistically significant difference was found between depth jump trials 3 and 10 as well as trials 4 and 10, during the 30 second rest interval length. This difference was attributed to either an experimenter error or subject motivation. The non-significant effects of rest interval length, number of jump trials, and interactive effects of rest interval length across 10 jump trials on the vertical ground reaction forces was attributed to the collection of only six complete data sets.

Conclusions

Within the limits of this study the following conclusion was made. A 15 second rest interval was a long enough period of recovery following depth jumps, since there was no significant differences in vertical jump heights or vertical ground reaction forces. Even though a significant difference was observed in vertical jump heights across the 10 jump trials during the 30 second rest interval length, there was no physiological explanation for this difference.

Weaknesses

The incomplete data set for the vertical ground reaction forces was a weakness in this study. Data sets were only complete for six of the 12 subjects. A complete set of forces for 12 subjects may have altered the results of the study. For the six incomplete subjects, some of the forces were missing after calculations were finished in the Peak Performance Motion Measurement System. This probably occurred due to an error by the researcher while collecting data.

Another weakness of the study was that the subjects had to report to the lab for four separate visits. Since the subjects had differing schedules, testing them at the same time of the day each visit was difficult. The other difficulty in testing the subjects was that each subject did not have the same number of rest days in between testing sessions. They all had a minimum of 24 hours between sessions, but some had as long as a week between testing sessions.

A final weakness of this study was the inability to control knee bend upon landing. For a stretch-shortening cycle to occur, minimal knee bend during the eccentric phase of landing is required to increase the utilization of elastic energy during the concentric phase or push off, leading to an increase in depth jump height. The subjects appeared to have different knee angles and since knee angle and stored elastic energy were not measured, it was unknown if utilization of the stretch-shortening cycle occurred in all subjects during all jump trials.

Recommendation for Future Research

Based on the outcome of this study, the following recommendations for future research were made. Future research should examine the effects of the same rest interval lengths used in the present study on depth jumps of multiple sets. Instead of testing one set of 10 depth jumps, two to three sets of depth jumps should be tested. Future research should examine the effects of shorter rest interval lengths on depth jumps. Interval lengths such as 5 and 10 seconds should be tested. Future research should use the same experimental design as this study, except test females, to examine if depth jump performance differs with different rest interval lengths. Finally, future research should examine the effects of rest interval lengths on other plyometric exercises, such as bounding or box to box jumps.

Practical Applications

Strength and conditioning coaches, track and field coaches, or any coach or professional who uses plyometrics in their training program, should be aware of the physiological effects of plyometrics to maximize both performance and safety. One way of maximizing performance is to ensure the athlete has sufficient rest between sets to allow the regeneration of ATP and CP. It was demonstrated in this study that 15 seconds rest was a long enough recovery period for consistent performance in the depth jump, as measured by the vertical jump heights and vertical ground reaction forces. Other plyometrics exercises of similar intensity and duration can also use 15 second rest periods. Plyometric exercises of longer duration, such as multiple jumps, may need to use longer rest periods. Depending on the number of jumps, rest periods of 30 to 60 seconds may need to be used.

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APPENDIX A

HEALTH SCREENING QUESTIONNAIRE

Appendix A

San Jose State University

Department of Human Performance

Health Screening Questionnaire

Name ______________________ Home Phone ____________

Home Address ________________________________

Personal Physician ____________ Physician's Phone __________

Age: ____ yr Weight: ____ kg

Height: ____ cm Gender ______

Leg length: ____ cm

Joint-Muscle Status (Check areas which you currently have problems).

Joint Areas

( ) Hips

( ) Knees

( ) Ankles

( ) Feet

( ) Other________

( ) Other________

Muscle Areas

( ) Abdomen

( ) Lower back

( ) Buttocks

( ) Thighs

( ) Lower leg

( ) Other________

( ) Other________

Physical Examination History:

Date of your last physical examination__________

Physical problems noted at that time__________

Has a physician ever made any recommendations to limit your levels of physical activity? Yes ( ) No ( ). If yes, what was recommended?__________________

____

Exercise Experience

Are you currently on a weightlifting program? Yes ( ) No ( ). If yes, how many years experience? _________

How many days a week do you lift weights? _________

How many days a week do you perform lower body weightlifting exercises?

____

What is the maximum amount of weight you can squat? _________

What is the maximum amount of weight you can leg press? _________

Are you currently on a sprinting program? Yes ( ) No ( ). If yes, how many times a week are you participating in the sprinting program? _________

Do you have any experience with plyometric training (or jump training)? Yes ( ) No ( ). If yes, are you currently on a program? Yes ( ) No ( ). If yes, how many times a week are you participating in the plyometric program? ________

APPENDIX B

INFORMED CONSENT FORM

Appendix B

Investigator: Mac Read

Title: The Effects of Varied Rest Interval Lengths on Depth Jump Performance.

Invitation to Participate

You are invited to participate in a study that will measure the effects of different rest interval lengths on vertical jump height and ground reaction forces during a depth jump. This study requires you to report to the exercise physiology laboratory (SPX 208) on four different occasions.

Requirements for Selection

You will be selected to participate in this study if you are a healthy male between 20 and 29 years of age and have a minimum of 1 year of weightlifting experience.

Testing Procedures

Explanation of a Depth Jump

A depth jump involves dropping from a predetermined height and upon landing, jumping vertically as high as possible.

Optimal Depth Jump Height

This test will involve the measurement of vertical jump height and ground reaction forces from a series of depth jumps from different heights, ranging from 10 - 80 cm, with an increase of 10 cm per jump. The height in which you achieve your highest vertical jump will be your optimal depth jump height.

Initials _____

Rest Interval Lengths

The next three laboratory visits will include performing a set of 10 depth jumps with a rest interval length of either 15, 30, or 60 seconds. Vertical jump height and ground reaction forces will be measured for each jump.

Discomforts and Risks

During the performance of depth jumps you may experience an increase in heart rate, blood pressure, breathing rate, and muscular fatigue. After the testing sessions you may experience some muscular soreness.

Benefits from Participation in the Study

You will benefit from this study by receiving an evaluation of your depth jumping performance including vertical jump height, ground reaction force production, and anaerobic recovery. In addition, if you decide to continue participation in this type of activity, a plyometric training program will be provided for you.

Assurance of Confidentiality

At no time will your name be disclosed, including within the text of this thesis as well as during any subsequent presentation and/or publication of the data without your expressed written consent. The security of your confidentiality will be maintained, since the consent form and results will be separated and only the investigator will have access to this information.

Withdrawal from the Study

You may withdraw your consent to participate in this investigation at any time, including during the testing procedures, without prejudice.

Initials _____

<u>Inquiries</u>

If you have any question about participation in this investigation or about the testing procedures feel free to ask. If additional questions come up later, or in case of an emergency, call Mac Read 408-294-2775, Dr. Craig Cisar 408-924-3018, Dr. James Bryant 408-924-3010 and they will respond. In case of any complaints during or after the testing, you may contact Dr. Serena Stanford, Associate Academic Vice President of Graduate Studies and Research 408-924-2480.

<u>Consent</u>

After reading the above, I agree that:

(a) My consent is voluntary.

(b) I understand the procedures.

(c) I know the potential risks and/or discomforts.

(d) I can withdraw from participation at any time, without any prejudice.

(e) I understand that the data is confidential and my identity will not be revealed without my expressed written consent.

(f) I agree to participate in this study.

MY SIGNATURE INDICATES THAT MY CONSENT IS VOLUNTARY AND I AGREE TO PARTICIPATE IN THIS STUDY UNDERSTANDING ALL THE INFORMATION PROVIDED TO ME IN THIS FORM.

You will be given a copy of this consent form for your personal records.

Participant signature________________________________ Date__________

Print your name____

Investigator signature____

APPENDIX C

WARM-UP PROCEDURE

Appendix C

Warm-up Procedure

The following exercises will be included during the warm-up. The bicycle ergometer will be used for 5 minutes at 50 RPM. Following the bicycle, a lower body stretch will be conducted, where each stretch is held for 15 seconds. The stretching exercises include a quadriceps stretch (pull heel towards buttocks), a hamstrings stretch (stand with legs apart, down to left, right and center), and a calves stretch (lean and press against wall). Three practice depth jumps will be executed from a height of 20 cm to familiarize the subjects with depth jumping.

APPENDIX D

VERBAL INSTRUCTIONS OF A DEPTH JUMP

Appendix D

Depth Jump Instructions

The subjects will be provided with a verbal explanation of the depth jumps. The following instructions will be provided to the subjects. The subjects will be instructed to keep their hands on their hips at all times, to step off the box, and to land on the force platform two feet at a time. Once they contact the force platform, they will be instructed to immediately jump as high as possible, by executing the jump as quickly and as explosively as possible. They will be instructed to land in the same spot they jumped from.

APPENDIX E

RESULTS SCORE SHEET

Results Score Sheet

Subject Number ________________ Age __________

Height __________cm Weight __________kg Leg length _________cm

DJ height	VJ height	forces
10 cm	_______	_____
20 cm	_______	_____
30 cm	_______	_____
40 cm	_______	_____
50 cm	_______	_____
60 cm	_______	_____
70 cm	_______	_____
80 cm	_______	_____

optimal height _______cm

15 sec	VJ height	force
1	_______	____
2	_______	____
3	_______	____
4	_______	____
5	_______	____
6	_______	____
7	_______	____
8	_______	____
9	_______	____
10	_______	____

30 sec	VJ height	force
1	_______	____
2	_______	____
3	_______	____
4	_______	____
5	_______	____
6	_______	____
7	_______	____
8	_______	____
9	_______	____
10	_______	____

60 sec	VJ height	force
1	_______	____
2	_______	____
3	_______	____
4	_______	____
5	_______	____
6	_______	____
7	_______	____
8	_______	____
9	_______	____
10	_______	____

rest interval order ____ ____ ____