MASTER'S THESIS

Effects of unilateral and bilateral lower body plyometric training on jump ability and agility performance of young female volleyball players

Kong, Tsz Yeung

Date of Award:
2018

HONG KONG BAPTIST UNIVERSITY

Master of Philosophy

THESIS ACCEPTANCE

DATE: June 5, 2018

STUDENT'S NAME: KONG Tsz Yeung

THESIS TITLE: Effects of Unilateral and Bilateral Lower Body Plyometric Training on Jump Ability and Agility Performance of Young Female Volleyball Players

This is to certify that the above student's thesis has been examined by the following panel members and has received full approval for acceptance in partial fulfillment of the requirements for the degree of Master of Philosophy.

Chairman: Prof. Lau Patrick W C
Professor, Department of Physical Education, HKBU
(Designated by Dean of Faculty of Social Sciences)

Internal Members: Prof. Cheung Siu Yin
Professor, Department of Physical Education, HKBU
(Designated by Head of Department of Physical Education)

Dr. Louie Lobo H T
Associate Professor, Department of Physical Education, HKBU

External Members: Prof. WONG Heung Sang Stephen
Professor
Department of Sports Science and Physical Education
The Chinese University of Hong Kong

Issued by Graduate School, HKBU

Effects of Unilateral and Bilateral Lower Body Plyometric Training on Jump Ability and Agility Performance of Young Female Volleyball Players

KONG Tsz Yeung

A thesis submitted in partial fulfillment of the requirements

for the degree of

Master of Philosophy

Principal Supervisor:

Dr. LOUIE Hung Tak, Lobo (Hong Kong Baptist University)

June 2018

DECLARATION

I hereby declare that this thesis represents my own work which has been done after registration for the degree of MPhil at Hong Kong Baptist University, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications.

I have read the University's current research ethics guidelines, and accept responsibility for the conduct of the procedures in accordance with the University's Committee on the Use of Human & Animal Subjects in Teaching and Research (HASC). I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants.

Signature: ________________

Date: June 2018

ABSTRACT

The purpose of this study was to examine the effects of 8-week unilateral and bilateral plyometric training program on jump ability and agility performance of young female volleyball players. Secondary school female volleyball players (N = 62, age = 14.56 ± 1.45 years, height = 159.14 ± 6.57 cm, weight = 53.55 ± 9.03 kg) were randomized and divided into three groups: the unilateral plyometric training group (UP), the bilateral plyometric training group (BP), and the control group (CON). For the UP and BP, the subjects completed 15 unilateral or bilateral plyometric training sessions over 8 weeks in addition to the regular volleyball training. For the CON, the subjects performed the regular volleyball training only. Pre-test and post-test were performed by all subjects before and after the intervention. The jump ability and agility performance were assessed by countermovement vertical jump (CVJ: double legs, right leg, and left leg), squat jump (SJ), 5 repeated block jumps (RBJ), standing long jump (SLJ), and T agility test. 2-way ANOVAs with repeated measures (3 groups x 2 times) were used to analyze the data. The results indicated that CVJ (right leg and left leg), RBJ, SLJ, and T agility test performance significantly increased ($p < .05$) after 8 weeks for both unilateral and bilateral training, but there were no differences ($p > .05$) between groups. Interaction effects ($p < .05$) existed for the CVJ (right leg), RBJ, and T agility test, indicating that from pre-test to post-test the UP had greater improvement than the CON. The CVJ (double legs) and SJ did not differ ($p > .05$) among types of training or from pre-test to post-test. It can be concluded that both unilateral and bilateral training are effective on improving most of the performance outcomes, but one program is not significantly better than the other in improving the jump ability and agility performance.

ACKNOWLEDGEMENTS

I would like to express my greatest gratitude to my principal supervisor, Dr. Louie Hung Tak, Lobo, for his support, valuable advices and professional suggestions and guidance throughout the whole study. I would also like to thank you my co-supervisor, Dr. Chen Kuan Chou, Kenneth, for his professional advices that definitely improved the quality of my thesis.

Finally, I would like to give special thanks to all subjects for their help in the study. Without their enthusiastic participation, this research might not have been made possible and successful.

Kong Tsz Yeung

June 2018

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

CHAPTER 1

INTRODUCTION

Background

Volleyball is an anaerobic sport that combines explosive movements with short periods of rest. Jumping activities in the sport of volleyball can include both horizontal approach movements and movements with no approach (Sheppard et al., 2008). Countermovement jump ability and approach jump ability are key components in spiking, jump setting, blocking and jump serving. Several training methods are effective in increasing vertical jump height. A combination of bodyweight plyometrics including countermovement jumps, depth jumps and squat jumps have been shown to result in a 4.7 to 15% increase in vertical jump height (de Villarreal, Kellis, Kraemer, & Izquierdo, 2009).

According to Peterson et al. (2006), muscular power is exhibited by all muscle actions that produce a velocity and may be defined as the rate of muscular force production, throughout a range of motion. Muscular power is considered necessary for sports such as volleyball because an increase in power enables a given muscle to produce the same amount of work in less time or a greater magnitude of work in the same time, which is involved in sprinting and jumping (Peterson et al., 2006). The use of plyometrics is an important training modality for power development.

Plyometric exercises have been widely used to improve power production and are highly correlated with athletic performance especially in sprinting and jumping. The stretch-shortening cycle (SSC) is one possible mechanism that explains the effectiveness of plyometric exercises (Wilson & Flanagan, 2008). The principle of utilizing SSC to increase the power of subsequent movements can be explained by activating the natural elastic components of muscles and tendon as well as the stretch reflex. When utilizing a rapid eccentric muscle action immediately followed by a concentric contraction, the activated muscle can produce higher force in the concentric phase. Therefore, exercises activating the SSC such as jumping are widely applied in training recently (Baechle & Earle, 2008). Jumping exercises can be classified under different approaches, whether they are performed bilaterally or unilaterally. Single leg exercises can be performed by using right and left legs alternately, or by repeating with one leg only (Baechle & Earle, 2008). Both methods are commonly used in varying amounts in volleyball and many other sports trainings. The fact that plyometric training is usually not performed in isolation type of exercise. The comparison of the effects of unilateral and bilateral plyometric training seems to be more useful as volleyball players require both single leg and double leg jump depending on their playing position and tactic. Implementing the most effective training stimulus and exercises should be the goal when developing sport specific characteristics in volleyball players. Moreover, based on the phenomenon of bilateral deficit that occurs in jumping, it is tempting to hypothesize that power training performed with each leg separately may allow greater loads and thus greater adaptations compared to bilateral training (Bobbert, de Graaf, Jonk, & Casius, 2006). Therefore, the magnitude of training effects of unilateral and bilateral plyometric training is still questionable.

Vertical jump performance is an effective assessment tool because the height of the jump has been shown to correlate significantly with maximal power production relative to body mass (McClenton et al., 2008). Maximal force capacity, rate of force development, muscle coordination and the ability to utilize the SSC are all factors that determine vertical jump performance (Arabatzi et al., 2010). Assessing lower body muscular power with valid and reliable field tests is important for strength and conditioning professionals (Markovic, Dizdar, Jukic, & Cardinale, 2004). According to Markovic et al. (2004) countermovement vertical jump and squat jump measured with a Just Jump! mat (Probotics, Inc., Huntsville, AL) are the most reliable and valid field tests for assessing explosive power in the lower body of physically active men. Kenny, Caireallain, and Comyns (2012) indicated high test-retest reliability for both the countermovement vertical jump and squat jump when measured with a Just Jump! mat.

It would be important to know the effect of unilateral and bilateral jump exercises because these types of body muscle movement are present during volleyball games. Researchers found that a significant greater performance was observed in power and jumping ability after 6 weeks of unilateral plyometric training but not after bilateral plyometric training (Makaruk, Winchester, Sadowski, Czaplicki, & Sacewicz, 2011). Makaruk et al. (2011) pointed out that single leg plyometric training resulted in greater improvement in unilateral compared to bilateral jumping tests, whereas bilateral training showed a similar improvement in both unilateral and bilateral test. Similar findings were reported by Delcore, Mathieu, Salazar, and Hernandez (1998), the researchers also indicated that unilateral plyometric exercises are more effective in improving power outcomes in bilateral tests. Comparing with bilateral training, unilateral exercises had equal effectiveness to improve the unilateral and bilateral leg strength and power (McCurdy, Langford, Doscher, Wiley, & Mallard, 2005) or even significantly led to longer contact times, lower vertical ground reaction forces, and rate of force development (Cappa & Behm, 2011).

As a result, there is a lack of results agreement on the effects of unilateral and bilateral plyometric training on power ability in both unilateral and bilateral test performance. More research is needed to compare the effect of unilateral and bilateral plyometric training on variables such as vertical power, horizontal power, and agility. Utilization of either bilateral or unilateral plyometric training is important to consider when designing a program to improve the sport specific characteristics of an individual volleyball player. Individual improvements may lead to better performance and success for the team. Therefore, the purpose of this research study was to examine the effects of 8-week unilateral and bilateral plyometric training program on jump ability and agility performance of young female volleyball players. The researcher hypothesized that the subjects who received unilateral plyometric training would have better performance than bilateral training group on unilateral power test and agility test, while the subjects who received bilateral plyometric training would have better performance than unilateral training group on bilateral power test.

Purpose of the Study

The purpose of present study was to examine the effects of 8-week unilateral and bilateral plyometric training program on jump ability and agility performance of young female volleyball players.

Definition of Terms

The following terms are used in the current study:

Countermovement Vertical Jump (CVJ)

The CVJ is defined as a movement in which the participant starts in an upright position with feet hip-width apart. From the upright position, a fast downward movement to about 90° knee flexion is immediately followed by a vertical jump (Sattler, Sekulic, Hadzic, Uljevic, & Dervisevic, 2012). In the context of this study, the CVJ was measured using the Just Jump contact mat. The Just Jump contact mat is an electronic mat connected to a handheld computer device measuring flight time created by Probotics, Inc. (Leard et al., 2007).

Plyometric Training

According to Turner, Owings, and Schwane (2003), plyometric training is a type of training that is used to enhance the ability of muscles to generate power. Plyometric training exaggerates the SSC by using the movement such as jumping, hopping, and bounding.

Power

Baechle and Earle (2008) defined power as the ability of muscle tissue to exert high force while contracting at a high speed.

Squat Jump

Squat jump (SJ) is defined as a movement in which the subject starts in a stance with 90° knee flexion, feet hip width apart and hands on hips. From the static position, subjects perform a vertical jump (Sattler, Sekulic, Hadzic, Uljevic, & Dervisevic, 2012).

Standing Long Jump (SLJ)

SLJ is defined as the movement that starts from standing position, with two-leg takeoff forward and ends with landing on both feet (Lorger, Hraski, & Hraski, 2012).

Stretch-Shortening Cycle (SSC)

Turner and Jeffreys (2010) defined SSC as an eccentric phase or stretch followed by an isometric transitional period called the amortization phase, and immediately followed by an explosive concentric action.

Delimitations of the Study

The study was delimited by the following factors:

1. Subjects were delimited to the secondary school female volleyball team players.

2. The plyometric training program coincided with the regular volleyball training of the subjects.

3. Subjects missed three or more sessions of plyometric training were not considered for the study.

4. The plyometric training were carried out at the school playground, outdoor park, or indoor sport center depending on the venue of volleyball training of the schools.

Limitations of the Study

The following limitations were considered when interpreting the current study:

1. Although subjects were advised to refrain from heavy physical activity 48 hr prior to the test days in order to eliminate the effect on the assessment, the researcher was unable to control for this factor.

2. The attitude and the motivation of subjects toward the tests and training cannot be controlled.

3. The performance of the subjects might be affected by their physical activity pattern and the physical lifestyle such as the sleeping hours before performing the tests and training.

4. The intensity of regular volleyball training cannot be controlled by the researcher.

5. The results may be limited by the reliability and validity of the assessments and

equipment.

Hypothesis

The following hypotheses were tested for the seven dependent variables: bilateral countermovement vertical jump, unilateral countermovement vertical jump (left leg), unilateral countermovement vertical jump (right leg), squat jump, 5 repeated block jumps, standing long jump, and T agility test.

1. There would be no significant mean difference in the seven dependent variables among three training groups (unilateral, bilateral, and control).

2. There would be no significant mean difference in the seven dependent variables between two test occasions (pre-test and post-test).

3. There would be no significant interaction among training groups and test occasions with regards to the seven dependent variables.

Significance of the Study

According to Powers (1996), vertical jump ability is critical for success in volleyball as jumping is always performed during the jump set, jump serve, blocking, and spiking. Therefore the ability to generate power in a very short period of time is important for a volleyball player to achieve higher level of performance in a game.

As specificity is important for training-induced adaptations, performance changes in explosive neuromuscular actions may require specific training strategies and must consider the unilateral and bilateral nature of competitive sport actions (Ramírez-Campillo, 2015). It would be important to know the isolated effect of unilateral and bilateral exercises because these two modes of muscle action are present during volleyball games.

If unilateral or bilateral power are particularly important for the volleyball players, due to the specificity of adaptations a high portion of drills in training could be executed with the required movement pattern. Moreover, coaches may target the worse leg more than the better leg in unilateral training to reduce asymmetry between legs by obtaining the results of this study.

During the competition phase, training time must be used efficiently. Unilateral and bilateral plyometric training have both been shown to increase peak power and improve vertical jump height (Cappa & Behm, 2011; Makaruk et al., 2011; McCurdy et al., 2005). The most efficient training method to improve lower body explosive power should be used to save the coach valuable time. According to the playing position, certain players may execute single leg jumps more than double leg jumps during the games. Moreover, blocking and agility are also important elements during the games, thus 5 repeated block jumps and T agility test were included in the assessment. Few studies exist regarding which training method is more effective in enhancing jump performance and agility in female volleyball athletes.

CHAPTER 2

REVIEW OF LITERATURE

Volleyball is an anaerobic sport that combines explosive movements with short periods of rest. High intensity bouts happen frequently to players in the frontcourt during offensive and defensive jumping bouts (Sheppard et al., 2008). The ball takes about 1.2-1.4 s to cover from one side to the other side of the court, which requires the players to adjust their body position quickly (Borras, Balius, Drobnic, & Galilea, 2011).

Katić, Grgantov, and Jurko (2006) mentioned that modern volleyball is characterized by a very high outreach of volleyball players above the net and high ball velocity on jump service and spiking. A very high speed of reaction and agility are required to be able to control such balls on serve reception, especially in field defense. The researchers pointed out that many research consider motor abilities, agility, and explosive power as the major characteristics for successful volleyball performance.

Gabbett, Georgieff, Anderson, and Cotton (2006) stated that volleyball players require well-developed speed, agility, upper body and lower body muscular power during a game. They conducted a study investigating the effect of a skill-based training program on both skill and physical fitness measurement in volleyball players. The findings showed that the skill-based volleyball training improved spiking, setting, and passing accuracy and spiking and passing technique after eight weeks training program, however no positive effects on the physiological characteristics of the players. Therefore the researchers suggested that upper and lower body power training program, especially the hip, knee, and ankle extensor power for blocking and spiking skills should be implemented in the volleyball players in order to enhance their physical performance and the long-term development of talent-identified volleyball players.

Jumping activities in the sport of volleyball include both horizontal approach movements and movements with no approach (Sheppard et al., 2008). Countermovement jump ability and approach jump ability are key components in spiking, jump setting, blocking, and jump serves. Therefore players can directly score by greater countermovement jump and approach jump ability, while other jump-related movements such as sprinting and sidestepping have supporting performance enhancement characteristics (Voelzke, Stutzig, Thorhauer, & Granacher, 2012). Each player on the court, with the exception of the libero, performs a high number of jumps each match. On average, in a 5 set match at the elite level, setters jump 136 times, middle hitters jump 97 times, opposite hitters jump 88 times, and side hitters jump 65 times (Borras et al., 2011). Due to the high volume of jumping in the sport, many coaches use countermovement jump and approach jump as an assessment tool to measure muscular power and jump height (Borras et al., 2011; Channell & Barfield, 2008; Sheppard et al., 2008). The strength and conditioning coach uses information retrieved from countermovement jump and squat jump along with other variables, to ensure appropriate exercise prescription to support successful performance in volleyball.

A combination of bodyweight plyometrics including: countermovement jumps, depth jumps, and squat jumps are an effective method for increasing vertical jump height (May, Cipriani, & Lorenz, 2010; McClenton, Brown, Coburn, & Kersey, 2008; de Villarreal et al., 2009). Plyometrics have been shown to result in a 4.7 to 15% increase in vertical jump height (de Villarreal et al., 2009). Increase in vertical jump height could be due to enhanced coordination and an increase in muscular power after training (de Villarreal et al., 2009). Gehri, Ricard, Kleiner, and Kirkendall (1998) conducted a study to determine which plyometric training technique including countermovement jump and depth jump is best for improving vertical jump ability. After 12-week program both training technique groups significantly increased vertical jump height but the depth jump group had a better results in improving all three types of jump measurement: squat jump, countermovement jump, and depth jump.

During the competition phase, training time must be used efficiently. Unilateral and bilateral plyometric training have both been shown to increase peak power and improve vertical jump height (Cappa & Behm, 2011; Makaruk et al., 2011; McCurdy et al., 2005). The most efficient exercise to improve lower body explosive power should be used to save the coach valuable time. The review of literature for the present study is focused on the following aspects: plyometric training, measuring and assessing lower body power, unilateral and bilateral training, and a summary.

Plyometric Training

Plyometric exercise defined as activities that empower a muscle to reach maximal force in the shortest possible time (Baechle & Earle, 2008). Plyometric exercise is a quick, powerful movement utilizing a pre-stretch or countermovement that involves the SSC. The SSC is a phenomenon where an activated muscle experiences a rapid eccentric muscle action then immediately followed by a concentric phase to produces high force (Makaruk et al., 2011). By using the natural elastic components of muscles and tendon as well as the stretch reflex, the power of subsequent movements can be increased through plyometric training.

The proper function of all active muscles and the speed of the muscular forces are the important elements for functional movements and athletic success in sports. This force-speed relationship can be defined as power, which can be improved by the use of plyometric training (Baechle & Earle, 2008). According to Chelly et al. (2010), the SCC during plyometric training is the combined action that involves stretching the muscle immediately before making a rapid concentric contraction. The use of the SSC is an appropriate training method for volleyball players because they must frequently jump, run, shuffle, and change of direction. According to Makaruk et al. (2011), Plyometric exercises have been widely used to improve power production and are highly correlated with athletic performance especially in sprinting and jumping. Johnson, Salzberg, and Stevenson (2011) also pointed out that plyometric training programs were effective for pubertal children to improve running speed, jumping ability, and strength. They also indicated that muscle performance and coordination of muscle groups can be improved by strength training however children would benefit more from plyometric training for improving the motor ability to run, jump, hop, skip, kick, and throw because of the similarity to sport skills and performance.

According to Lehnert, Lamrova, and Elfmark (2009) the advantage of plyometric training is that it increases functional power and allows the muscles to reach a higher power level than the maximum volitional power. The countermovement jump (CMJ) is used to measure vertical power (Boraczynski & Urniaz, 2008; Cherif, Chaatani, Nejlaoui, Gomri, & Abdallah, 2012; Lockie, Murphy, Schultz, Knight, & Janse de Jonge, 2012). The CMJ begins from an upright position then a downward movement is made to a knee angle of 90°, then a push-off movement, and ending with landing position (Chelly et al., 2010). According to Lockie et al. (2012), the CMJ was correlated to superior performance during the acceleration of sprint and is suitable to be used as an indirect measure of vertical power.

Lockie et al. (2012) examined four different protocols in a study including free sprinting (FST), weight training (WT), plyometric training (PT), and resisted sprint training (RST). The study assessed changes in acceleration kinematics, power, and strength in field sport athletes. Participants included 35 men who were currently participating in a field sport. Lower body strength was assessed using a 3 RM squat test and lower-limb power was assessed using the CMJ. The WT and PT groups increased approximately 10% in the 5- to 10-m velocity. All groups significantly increased absolute strength and relative strength in 3 RM squat. The PT group indicated greater muscle stretch-shortening capacity during rebound from impacts. An important consideration and finding in this study is that field sport athletes can develop horizontal and reactive power from weight and plyometric training besides power in the vertical plane. Step length in all groups increased, which signifies sprint-specific gains in horizontal power.

Chelly et al. (2010) conducted an 8-week study on the addition of a lower limb plyometric training program consisting of hurdle and depth jumping combined with a soccer training program. 23 male participants were randomly assigned to a control group (normal training) and an experimental group (normal training combined with biweekly plyometric training). The squat jump and countermovement jump were used to assess leg power, a 5-m and a 40-m sprint time was used to assess velocity. jump test scores were increased and a significant increase of running velocities were found ($p < .001$). The findings indicate that the plyometric training program increased several measures of potential soccer playing performance. Countermovement jump was increased by 4.2%. It is suggested that plyometric training improves coordination and elicits neuromuscular adaptation that enhances power production. Neuronal adaptations include selective activation of muscles and motor units, synchronization, and increased recruitment of motor units (Chelly et al., 2010). According to Johnson, Salzberg, and Stevenson (2011), evidences suggested that a twice a week plyometric program for 8 to 10 weeks beginning at 50-60 jumps a session and increasing repetitions weekly by 12-18 jumps to a maximum of 90-190 can have the largest improvement in jumping performance.

Measuring and Assessing Lower Body Power

In many sports, specifically volleyball, jumping is a basic activity performed by all the players except the libero, but is also a determining factor for the libero position because of the relationship between vertical jump height and quick movements (Borras et al., 2011). The libero must make quick lateral and linear movements to adjust body position to the ball position during receiving and defending (Borras et al., 2011). Lower body muscular power and strength is essential to complete quick body displacements (Borras et al., 2011). Vertical jump performance is an effective assessment tool because the height of the jump has been shown to correlate significantly with maximal power production relative to body mass (McClenton et al., 2008). Maximal force capacity, rate of force development, muscle coordination, and the SSC are the factors that determine vertical jump performance (Arabatzi et al., 2010).

Assessing lower body muscular power with valid and reliable field tests is important for strength and conditioning professionals (Markovic, Dizdar, Jukic, & Cardinale, 2004). According to Markovic et al. (2004) countermovement vertical jump and squat jump measured with a Just Jump! mat are the most reliable and valid field tests for assessing explosive power in the lower body of physically active men when compared to other types of jump such as Sargent jump, Abalakow's jump with and without an arm swing, and standing long jump. Markovic et al. (2004) concluded a high test-retest reliability for the countermovement jump and squat jump (α = 0.98 and 0.97, respectively). Kenny, Caireallain, and Comyns (2012) indicated a high test-retest reliability for both the countermovement vertical jump and squat jump. The squat jump and countermovement vertical jump have similar biomechanical characteristics (Markovic et al., 2004).

Concentric strength is measured by the squat jump, because the pre-stretch is eliminated, whereas the countermovement vertical jump has the effect of the pre-stretch (Markovic et al., 2004). The squat jump test and countermovement vertical jump test start in different positions. The squat jump test starts with the subjects in a stance with 90° knee flexion, feet hip-width apart, and hands on hips (Sattler et al., 2012). From the static position, the subjects perform a vertical jump eliminating any pre-stretching. The countermovement vertical jump begins with the subjects in an upright stance, feet hip width apart, and hands on hips (Sattler et al., 2012). From the upright position, a fast downward movement to about 90° knee flexion is followed by a vertical jump immediately (Sattler et al., 2012). The pre-stretching movement is a characteristic of a countermovement vertical jump

(Sattler et al., 2012).

The performance of a block jump is strongly correlated to the performance of a countermovement vertical jump (Sattler et al., 2012; Sheppard et al., 2008). Peak power per kilogram of bodyweight is strongly related to vertical jump height (Carlock et al., 2004). Volleyball is associated with lifting only body mass, so the countermovement vertical jump test that measures peak power per kilogram of bodyweight should be used (Carlock et al., 2004).

Currently there are two very popular devices when evaluating countermovement vertical jump and squat jump performance in volleyball teams: the Vertec (Sports Imports, Columbus, OH) and the contact mat also known as a Just Jump! Mat (Probotics, Inc., Huntsville, AL Sattler et al., 2012). According to Borras et al. (2011), information obtained from the Vertec and Just Jump! mat is different. Vertec is used to evaluate hand height, whereas the Just Jump! mat is used to evaluate the center of mass height (Borras et al., 2011). Electronic mats (i.e., Just Jump!) are generally more efficient because the reach of the athlete does not need to be measured (Kenny et al., 2012).

The Vertec is made out of a steel frame and a height scale consisted of horizontal vanes that are displaced by the subject when jumping (Borras et al., 2011). The height is calculated by taking the difference between the reach of the subject and the highest possible vane displaced by the subject (Borras et al., 2011). Importantly, The Vertec is limited to jumps with arm movement (Borras et al., 2011).

The Just Jump! mat is used to predict the jump height by calculating the flight time (Aragón, 2000). Microswitches embedded in the Just Jump! mat calculate the time period between the takeoff and landing of the subject (Isaacs, 1998). According to Leard et al. (2007) the mat is attached to a handheld computer that records time in the air and displays the height of each jump, which can limit the human error. Leard et al. (2007) indicated that the Pearson r between the 3-camera motion analysis system and Just Jump! mat was 0.97 and the Pearson r between the Vertec and the 3-camera motion analysis system was 0.91. Leard et al. (2007) concluded that the Just Jump! mat is a more valid test than the Vertec in measuring vertical jump height due to the high correlation and the minimal difference in means between the Just Jump! mat and 3-camera System. Kenny et al. (2012) concluded the Pearson r between the Just Jump! mat and force platform was 0.99 for the countermovement vertical jump and 0.96 for the squat jump. Kenny et al. (2012) showed valid results of the countermovement vertical jump and squat jump tests measured by a Just Jump! mat when comparing to the measurements from a ground mounted strain gauge force platform. Data obtained from a countermovement vertical jump and squat jump test can be helpful for identifying positions at which a given athlete may have the best chance of success (Sattler et al., 2012).

Unilateral and Bilateral Training

Jones et al. (2012) indicated that consistent training with the back squat was evidenced to improve lower body strength and power in both men and women, therefore athletic performance can be improved. However, the movement in most ground-based or field sports was generally producing force by single leg, like running, kicking, bounding, changing direction, and jumping. Thus, including unilateral training into a strength training program should be considered. According to McCurdy et al. (2005) many skills rely on fundamental lower body movements such as running are performed unilaterally. Therefore, for better performance improvement the resistance exercises that closely mimicked the mechanics and forces requiring to perform the necessary skills in the sport should be used.

Jones et al. (2012) investigated the differences in muscle activation and testosterone concentrations during a bilateral and unilateral lower body heavy resistance exercise (HRE). The bilateral exercise used was the back squat (BS) while the unilateral exercise used was the pitcher squat (PS). Jones et al. (2012)

compared the effects of unilateral and bilateral lower body HRE on muscle activity measuring by surface electromyography (sEMG) and testosterone (TES) concentrations. Subjects included 10 resistance-trained male collegiate athletes. Muscle activity of the biceps femoris, erector spinae, gluteus medius, and vastus lateralis of the right leg were recorded via sEMG during exercises. By collecting the blood samples at baseline and 0, 5, 10, 15, and 30 min post-exercise, the TES was recorded. For the assessment, Session 1 and 2 were used for determining the predicted maximal strength with the 10-repitition (10 RM) bilateral (BS) and unilateral (PS) tests. Session 4 and 5 were used to collect blood samples during 4 sets of the 10 RM BS and PS exercises.

Jones et al. (2012) found that no difference between the two modes of lower body exercise (BS and PS). Muscle activity was similar between the two modes in terms of relative loads. During the BS, weight distribution may be balance over two legs while weight distribution is unilaterally biased during the PS, which placed additional stabilization demands upon the neuromuscular system. Thus, although having less absolute work volumes in PS, the subjects still had similar muscle activation levels to BS. This indicated the relative loads may have been comparable between the two exercises. No significant differences (p = .80) were observed in muscle activation amplitudes between BS and PS exercises. Total

TES levels increased during HRE for both BS and PS so it can be suggested that both exercises are physiologically demanding. Jones et al. (2012) concluded that although the absolute load of the unilateral leg training may be lower than the double leg training, the relative intensity may be greater than or equal to that of bilateral leg training, therefore resulted in better force development of single leg and greater sport-specific strength gains. Jones et al. (2012) suggested that relative strength gains utilizing unilateral exercises such as the PS may relate more to improving acceleration needed for field sport athletes.

McCurdy et al. (2005) also determined that regular training with unilateral exercises, such as the pitcher squat (PS) had similar effectiveness to bilateral exercise (BS) in untrained men and women. Jones et al. (2012) established that a unilateral multi-joint, dynamic exercise such as the PS was just as effective as the BS for enhancing muscle activity and testosterone changes. Jones et al. (2012) stated that neuromuscular adaptations are specific to the exercise selection as they found that regular resistance exercise training led to higher muscle activity for the selected exercises. The neuromuscular adaptations depicted through unilateral or bilateral exercises may relate to sport specific skills such as the unilateral nature of sprint performance (Jones et al., 2012).

McCurdy et al. (2005) compared the effects of short term unilateral resistance training (UL) and bilateral resistance training (BL) with free weights on several tests of strength and power. The UL group trained with core unilateral exercises included lunges, step-ups, and pitcher squats while the BL group trained with core bilateral exercises such as front squats and back squat. A post-test was conducted after eight weeks of training to examine early phase changes in strength and power for UL and BL. Subjects included 23 men and 16 women with the ages between 18 and 24 who had not participated in lower body resistance training within a year before the study. A 2-week instructional period were given to the subjects to acquire proper technique with loads that were close to their 5 repetition maximum (RM) for the unilateral and bilateral squat. During Week 3 and 4 bilateral power was assessed by countermovement vertical jump with contact mats while unilateral power was assessed by the Margaria-Kalamen stair-climb test and the unilateral countermovement vertical jump. Strength was assessed using a 5 RM test to estimate the 1 RM using a 1 RM prediction chart. The BL group completed a barbell free-weight back squat and the UL group completed a unilateral squat.

After the instructional period and the testing period both UL and BL performed the resistance training program two days per week for eight weeks. Both unilateral and bilateral core exercises were used to maximize strength and power improvement. Training volumes and intensities were equal for both groups with progression throughout the eight weeks of training. The UL group performed unilateral plyometrics whereas the BL group performed bilateral plyometrics before the resistance training session two days per week. Each group did pogo jumps and countermovement vertical leaps for each session. The results found that the UL group improved the unilateral vertical jump height (p = .001) and relative power (p = .013) more than the BL group. For the strength, the UL and BL had similar improvement. McCurdy et al. (2005) concluded that UL and BL are equally effective for early phase improvement of unilateral and bilateral leg strength in untrained men and women, and UL had better improvement on unilateral power than BL. McCurdy et al. (2005) suggested that more information was still needed for the coaches to decide the amount of emphasis placed on including unilateral supported exercises in training programs to improve functional strength. Comparing to the bilateral leg exercises, the single-leg exercises had a higher relative intensity which is sufficient for improving strength even less total weight must be used to perform unilateral leg exercises. McCurdy et al. (2005) also suggested untrained subjects tended to have a greater potential to improve their strength due to neuromuscular adaptations and during unilateral assessment.

Makaruk et al. (2011) conducted a study on the effects of unilateral and bilateral plyometric training on power and jumping ability in women, which included 49 untrained women randomly assigned to one of three groups, unilateral plyometric group *(n* = 16), bilateral plyometric group *(n* = 18), and control group *(n* = 15). The alternate leg tests (10s Wingate test and 5 alternate leg bounds), bilateral countermovement vertical jump, and unilateral countermovement vertical jump were used to assess the peak power and jumping ability. The plyometric training programs involved single and double leg bounds with the same number of contacts with the ground and intensity between groups. The peak power, jumping height, and jumping distance were measured four times in total: pretraining, during week 7 (mid-training), post-training, and 4 weeks after the program (detraining). The researchers found that only the unilateral group produced significant improvement in all tests from pre-training to mid-training. Performance was maintained mid-training to post-training and decreased during detraining. On the other hand, the bilateral group improved in all tests from pre-training to post-training and did not decrease power and jumping ability in all tests during detraining. Researchers concluded that unilateral plyometric exercises may be more effective on improving power in a short period of training while bilateral plyometric exercises may help maintain high power production throughout a longer competition period.

For the practical application, Bogdanis et al. (2017) found that unilateral plyometric training of the lower limbs was two to three fold more effective compared with an equal volume of bilateral training when testing was performed with each limb separately after 6 weeks of twice-weekly training with a total of 1800 jumps. This large increase in single-leg explosive muscle performance could be useful for many individual and team sports that included high force single leg muscle actions, ranging from track and field jumping and sprinting to team sports. Coaches may incorporate unilateral plyometric lower limb exercises in their training programs for the athletes. Ramirez-Campillo et al. (2018) indicated that bilateral training provided advantages to improve change of direction, bilateral strength and jumping performance, while unilateral training induced greater gains in unilateral jumping. However, considering the unilateral nature of most competitive actions, including change of direction and to maximize adaptations among the young players, combining unilateral and bilateral drills, executed in different planes during training sessions was recommended.

Summary

Plyometric training, such as the depth jump, have been shown to increase vertical jump height (Bobbert, 1990; Jensen & Russell, 1985; McClenton et al., 2008; Sheppard et al., 2008; Verkhoshansky, 1968; de Villarreal et al., 2009; Voelzke et al., 2012). Plyometric exercises that utilized the SSC increased the power output of the athlete in the concentric phase (Arabatzi et al., 2010; Hori et al., 2005). The majority of the literature has focused on how plyometrics affect jump ability. However, few studies investigated the performance outcome differences between unilateral and bilateral plyometric training. Additional research is needed to compare the unilateral and bilateral plyometric training protocols on jump ability as well as agility performance.

CHAPTER 3

METHOD

This study was designed to address the question of which plyometric training mode is better for improving jump and agility performance in young female volleyball players. The aim of the present study was to examine the effects of 8-week unilateral and bilateral plyometric training program on jump ability and agility performance of young female volleyball players.

Subjects

In total 75 secondary school female volleyball team players with age between 12 and 17 from four secondary schools were recruited for the study. The subjects had no systematic strength or plyometric training for the last 6 months leading up to the study (less than one session per week). The subjects were randomized and divided into three groups: the unilateral plyometric training group (UP), the bilateral plyometric training group (BP), and the control group (CON). For the UP, 6 subjects from school A, 6 subjects from school B, 9 subjects from school C, and 4 subjects from school D; for the BP, 4 subjects from school A, 5 subjects from school B, 9 subjects from school C, and 3 subjects from school D; for the CON, 4 subjects from school A, 4 subjects from school B, 6 subjects from school C, and 2 subjects from school D. In addition to the school regular volleyball training, the UP and the BP performed a plyometric training session twice a week for 8 weeks. The CON performed the regular volleyball training only throughout the study. Subjects received written and oral information about the study design and measurement procedures. The possible risks and benefits of participating in the study were explained to the subjects before signing an informed consent. Exclusion criteria included athletes with potential medical problems or any history of injury that would affect their physical performance or the results of this study in the three months preceding the study. Subjects were asked to continue their normal daily lifestyle for the duration of the study.

Study Design and Training

The intervention period lasted for 8 weeks. During the study, subjects were instructed not to perform any other strength or plyometric training that might influence the results. Pre-test and post-test were performed immediately before and 3-5 days after the intervention period. For the UP and BP, the subjects completed 15 unilateral or bilateral plyometric training sessions over 8 weeks in addition to the regular volleyball training. For the CON, the subjects performed the regular volleyball training only. Subjects were trained two sessions a week and the sessions were at least 48 hrs apart. At least one certified strength and conditioning specialist led the sessions and supervised all the subjects with careful attention to proper exercise techniques. All plyometric training sessions were performed at the end of each regular volleyball training session. Each plyometric training session took approximately 30 min. Plyometric training for the UP included single leg exercises only and plyometric training for the BP included double leg exercises only, both with a progression in intensity and volume. In order to have the subjects be adapted and familiar with the plyometric training, the first two sessions were the same for both UP and BP, which only bilateral exercises were performed. Beginning from the third session, the training program content regarding the exercises, volume and intensity were changed every two sessions in order to make appropriate progression. Subjects were instructed to jump with maximal intensity for maximal height or distance and minimum contact time in every jump. These instructions were in order to maximize explosive strength requiring fast SSC. To equalize the volume and intensity of the training between unilateral and bilateral exercises, the number of contacts with the ground were the same for both groups. For example, bilateral group performed 4 sets of 10 double leg vertical jump while unilateral group performed 2 sets of 10 left leg vertical jump and 2 sets of 10 right leg vertical jump. Details of each session including the exercises, sets, repetitions, and rest between sets are shown as Appendix C.

Assessment and Equipment

Pre-test and post-test were performed by all subjects before and after the intervention. Subjects were asked to refrain from heavy physical activity 48 hrs prior to the test days in order to eliminate the negative effect on the assessment. The assessments were in the following order:

Countermovement vertical jump (double legs, right leg, and left leg). Subjects performed a countermovement vertical jump on a jump contact mat (Probotics, Inc., AL). For the double legs countermovement vertical jump, the subject started in an upright position with feet hip-width apart. From the upright position, a fast downward movement to about 90° knee flexion was immediately followed by a maximal effort vertical jump (Sattler, Sekulic, Hadzic, Uljevic, & Dervisevic, 2012). Arm swing must be performed for each jump. Subject performed two jumps with about 1 min rest in between, and two trials were recorded. The highest score was used for the analysis. The jump contact mat measured the flight time, time difference between takeoff and landing, and estimated the jump height. The jump contact mat had a high correlation and minimal difference in the means compared to the criterion reference 3-camera motion analysis system for a vertical jump (Leard et al., 2007). For the right leg and left leg countermovement vertical jump, subjects first stood on the mat and then slightly raised one foot off the mat to make sure jumping only by the single leg. The subjects can land with single leg or both legs. Two trials were recorded for each leg and the highest scores were used for analysis.

Squat jump. Subjects performed a squat jump on a jump contact mat. The subject started in a stance with 90° knee flexion, feet hip width apart and hands on hips. From the static position, subjects perform a vertical jump with arm swing (Sattler et al., 2012). Two trials with about 1 min rest in between were recorded and the best was used for analysis.

5 repeated block jumps. Subjects performed a 5 repeated block jumps on a jump contact mat. Subjects were required to jump as high as possible for 5 consecutive efforts without a pause between jumps (Cormack, Newton, McGuigan, & Doyle, 2008). The arms of the subjects should be always higher than the waist throughout the jumps, which imitated the block jumps occurred during the volleyball games. Countermovement depth was self-selected by the subject. Subjects performed the test once and the average height of 5 jumps was used for analysis.

Standing long jump. The test was performed on a smooth ground. A ruler was stuck on the ground to show the distance that the subjects jumped. Each subject stood on the starting line with her legs parallel and feet shoulder–width apart. Subjects were instructed to bend the knees (the depth of the flexion was self-selected) and bring the arms behind the body. Then, with a powerful drive the subject extended the legs, moved the arms forward, and jumped as far as possible. Subjects performed three jumps with about 1 min rest in between, and three trials were recorded. The highest score was used for the analysis. The length of the jump was assessed from the starting line to the heel that was closest to the starting line (Veligekas, Tsoukos, & Bogdanis, 2012).

T agility test. The T agility test was applied to measure agility during direction changes included forward sprints, left and right shuffles, and backpedaling (Miller et al., 2006). In this test three cones A, B, C were set five meters apart on a straight line from left to right and a fourth cone D was placed ten meters from the middle cone B, forming a T shape. Subjects began with both feet behind the starting line at cone D. Subjects sprinted forward 10 m to cone B and touched the cone with the right hand. Subjects then shuffled to the left 5 m and touched cone A with the left hand. Subjects then shuffled to the right 10 m and touched cone C with the right hand. Subjects then shuffled to the left 5 m back to cone B and touched it with the left hand. Subjects then ran backward, passing the finishing line at cone D. A warm-up trial was performed and one official trial was recorded. The time was measured in seconds (two decimal places).

Statistical Analysis

A pretest-posttest randomized groups experimental design was used. Standard statistical methods were used for calculation of means and standard deviation. The independent variables were the types of plyometric training: UP, BP, and CON. The dependent variables included the test results of bilateral countermovement vertical jump (CVJ), unilateral countermovement vertical jump (left leg) (CVJ-L), unilateral countermovement vertical jump (right leg) (CVJ-R), squat jump (SJ), 5 repeated block jumps (RBJ), standing long jump (SLJ), and T agility test. Normality and homoscedasticity assumptions for all data (pre-test and post-test) were checked respectively. To determine the effect of intervention, seven 2-way analysis of variance (ANOVAs) with repeated measures (3 groups x 2 times) were applied. If a significant F value is achieved between groups, Bonferroni post hoc procedures would perform to locate the pairwise differences between the means. Standardized effect sizes and percent change were conducted to examine the treatment effects. Statistical significance was set at $p = .05$, and the Statistical Package for the Social Sciences Version 24.0 for Windows (SPSS Inc., Chicago, IL) program was used for all statistical calculations.

CHAPTER 4

DATA ANALYSIS

Results

The purpose of present study was to examine the effects of 8-week unilateral and bilateral plyometric training program on jump ability and agility performance of young female volleyball players. A total of 62 female subjects (14 subjects from school A, 15 subjects from school B, 24 subjects from school C, and 9 subjects from school D) completed the 8-week intervention study. Out of 75 participants, 13 were excluded from the study due to the low attendance rate of the training (>2 sessions absence) or absence from the post-test. Descriptive statistics for age, height, and weight are presented in Table 1. The subjects completed a pre- and post-test along with 15 training sessions. Descriptive statistics for pre- and post-test sessions are presented in Table 2 and 3:

Table 1

Descriptive Statistics for Female Subjects (N = 62)

	UP (n = 25) *M ± SD*	*BP* (n = 21) *M ± SD*	*CON*(n = 16) *M ± SD*
Age (years)	14.56 ± 1.45	14.48 ± 1.50	14.69 ± 1.54
Height (cm)	159.14 ± 6.57	160.07 ± 4.34	157.44 ± 6.55
Weight (kg)	53.55 ± 9.03	51.80 ± 8.36	54.87 ± 9.92

Table 2

Training Effects for the Jump and Agility Performance Variables for the UP (n = 25), BP (n = 21), and CON (n = 16)

	Pre-test *M ± SD*	*Post-test* *M ± SD*
CVJ (cm)		
UP	34.70 ± 5.74	35.43 ± 6.60
BP	36.25 ± 3.69	37.54 ± 4.19
CON	35.28 ± 5.22	34.61 ± 4.10
CVJ-L (cm)		
UP	18.33 ± 3.71	20.35 ± 3.69*
BP	19.74 ± 3.59	21.95 ± 2.89*
CON	20.29 ± 3.90	21.08 ± 3.91
CVJ-R (cm)		
UP	19.30 ± 3.59	21.69 ± 4.07*
BP	21.64 ± 2.88	22.95 ± 3.19*
CON	21.14 ± 4.13	21.16 ± 3.96
SJ (cm)		
UP	33.38 ± 5.81	34.72 ± 6.69
BP	35.49 ± 4.09	36.02 ± 3.85
CON	34.23 ± 6.09	34.03 ± 5.74

RBJ (cm)		
UP	28.07 ± 4.83	29.97 ± 5.83*
BP	29.45 ± 3.93	31.00 ± 4.05*
CON	29.03 ± 4.15	28.93 ± 4.34
SLJ (cm)		
UP	169.88 ± 21.52	177.56 ± 21.44*
BP	172.29 ± 15.95	181.62 ± 17.80*
CON	168.13 ± 22.45	171.25 ± 20.45
T agility test (s)		
UP	14.30 ± 1.21	13.44 ± 1.00*
BP	13.68 ± 0.76	13.27 ± 0.88*
CON	14.04 ± 1.28	13.71 ± 1.04

*Sigificant ($p < 0.05$) pre- to post-test comparisons.

Table 3

Standardized Effect Sizes, Change, and Percent Change for the Jump and Agility Performance Variables for the UP (n = 25), BP (n = 21), and CON (n = 16)

	d	*Change*	*%Change*
CVJ (cm)			
UP	0.21	0.73	2.10%
BP	0.56	1.30	3.59%
CON	-0.29	-0.67	-1.90%
CVJ-L (cm)			
UP	0.78	2.02	11.02%
BP	0.82	2.21	11.20%
CON	0.35	0.79	3.89%
CVJ-R (cm)			
UP	0.72	2.39	12.38%
BP	0.63	1.32	6.10%
CON	0.01	0.02	0.09%
SJ (cm)			
UP	0.42	1.34	4.01%
BP	0.17	0.53	1.49%
CON	-0.09	-0.20	-0.58%
RBJ (cm)			

UP	0.68	1.90	6.77%
BP	0.90	1.55	5.26%
CON	-0.05	-0.10	-0.34%
SLJ (cm)			
UP	1.00	7.68	4.52%
BP	0.74	9.33	5.42%
CON	0.29	3.12	1.86%
T agility test (s)			
UP	-1.39	-0.86	-6.01%
BP	-0.66	-0.41	-3.00%
CON	-0.45	-0.33	-2.35%

Seven 3 x 2 mixed factorial ANOVAs were used to analyze the data. Group was an independent variable with three levels: UP, BP, and CON. Test occasion was the repeated measures variable with two levels: pre-test and post-test. Bilateral countermovement vertical jump (CVJ), unilateral countermovement vertical jump (left leg) (CVJ-L), unilateral countermovement vertical jump (right leg) (CVJ-R), squat jump (SJ), 5 repeated block jumps (RBJ), standing long jump (SLJ), and T agility test were the dependent variables. Age group differences (age 12-13, age 14-15, and age 16-17) have been analyzed but no differences were found. ANOVA summary tables can be found in Appendix D.

Analyzing the CVJ-R data, a significant mean difference was found from pre- to post-test for the groups (*F* (1, 59) = 12.79, *p* = .00). No significant differences *(p* > .05) in CVJ-R existed between groups. A significant interaction effect (*F* (2, 59) = 3.81, *p* = .03) was observed for the CVJ-R (Figure 1). UP experienced a greater improvement in CVJ-R following 8 weeks training compared to CON. The standardized effect size for test occasion was 0.72 for the UP and 0.01 for the CON. This indicates that the UP jumped higher with a 12.38% increase in the CVJ-R compared to the 0.09% increase in the CON.

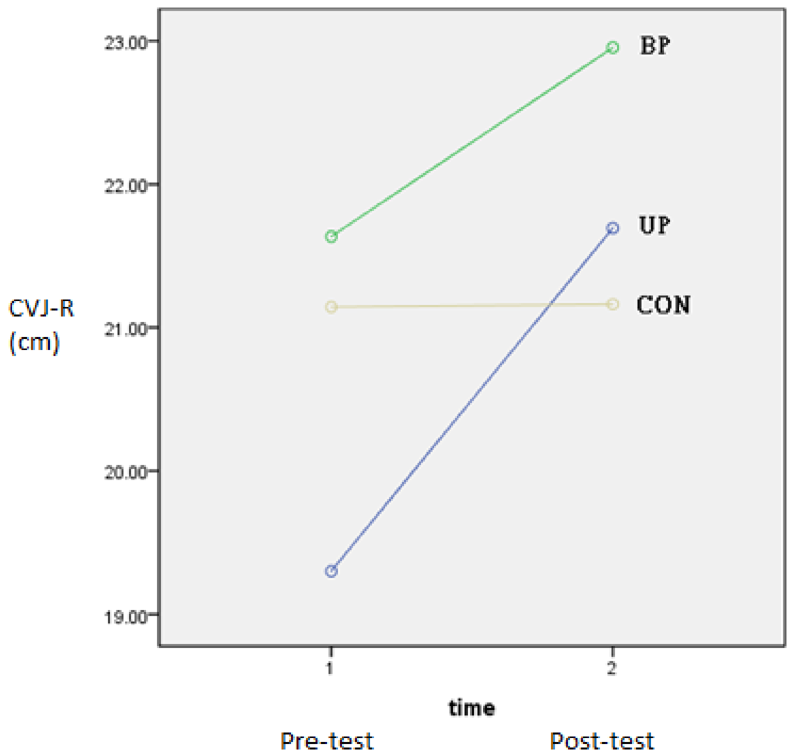

Figure 1

Line Graph Showing the Interaction Effect on CVJ-R among UP, BP, and CON

Analyzing the RBJ data, a significant mean difference was found from pre- to post-test for the groups (F (1, 59) = 14.43, p = .00). No significant differences (p > .05) in RBJ existed between groups. A significant interaction effect (F (2, 59) = 4.02, p = .02) was observed for the RBJ (Figure 2). UP experienced a performance gain in RBJ following 8 weeks training compared to a performance decrease in the CON. The standardized effect size for test occasion was 0.68 for the UP and -0.05 for the CON. This indicates that the UP jumped higher with a 6.77% increase in the RBJ compared to the 0.34% decrease in the CON.

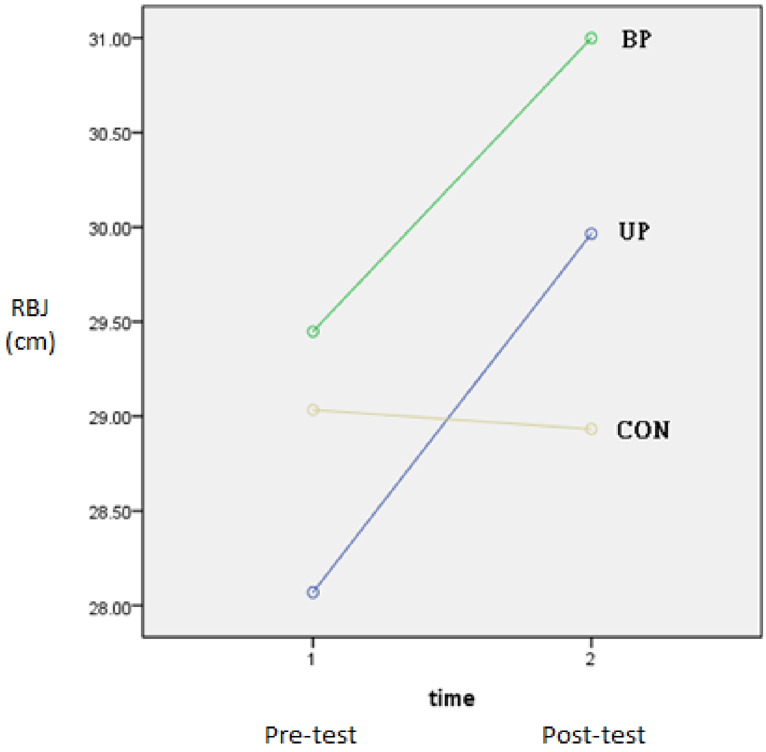

Figure 2

Line Graph Showing the Interaction Effect on RBJ among UP, BP, and CON

Analyzing the T agility test data, a significant mean difference was found from pre- to post-test for the groups (*F* (1, 59) = 40.09, *p* = .00). No significant differences (*p* > .05) in T agility test existed between groups. A significant interaction effect (*F* (2, 59) = 4.12, *p* = .02) was observed for the T agility test (Figure 3). UP experienced a greater improvement in T agility test following 8 weeks training compared to CON. The standardized effect size for test occasion was -1.39 for the UP and -0.45 for the CON. This indicates that the UP ran faster with a 6.01% decrease in the time of T agility test compared to the 2.35% decrease in the CON.

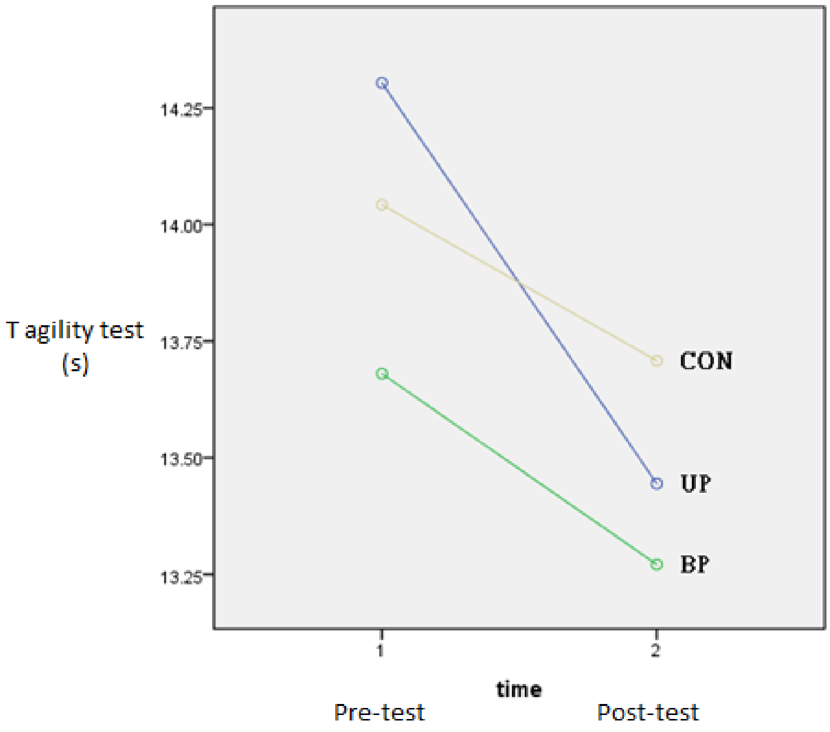

Figure 3

Line Graph Showing the Interaction Effect on T agility test among UP, BP, and CON

Analyzing the CVJ-L data, a significant mean difference was found from pre- to post-test for the groups (F (1, 59) = 25.86, p = .00). No significant differences (p > .05) in CVJ-L existed between groups. No significant interaction effect (p > .05) was observed for the CVJ-L. The UP had an increase of 11.02% in the CVJ-L from pre- to post-test. The BP had a 11.20% increase in CVJ-L from pre- to post-test.

Analyzing the SLJ data, a significant mean difference was found from pre- to post-test for the groups (F (1, 59) = 25.44, p = .00). No significant differences (p > .05) in SLJ existed between groups. No significant interaction effect (p > .05) was observed for the SLJ. The UP had an increase of 4.52% in the SLJ from pre- to post-test. The BP had a 5.42% increase in SLJ from pre- to post-test.

According to the ANOVAs, no significant main or interaction effects (p > .05) were found for the two dependent variables CVJ and SJ. For the CVJ, the UP had a 2.10% increase in the CVJ compared to the 3.59% increase in the BP, and a 1.90% decrease in the CON. This indicates a greater improvement in the BP in terms of the percentage change. For the SJ, the UP had a 4.01% increase in the SJ compared to the 1.49% increase in the BP, and a 0.58% decrease in the CON. This indicates a greater improvement in the UP when percentage change was considered.

Discussion

The present study was designed to examine the effects of 8-week unilateral and bilateral plyometric training program on jump ability and agility performance of young female volleyball players. The subjects in the study were 62 secondary school female volleyball players, between the ages of 12 and 17 years. CVJ-L, CVJ-R, RBJ, SLJ, and T agility test performance increased after 8 weeks for both UP and BP, but the findings proposed that one program was not significantly better than the other in improving the jump ability and agility performance. Significant interaction effects existed for the CVJ-R, RBJ, and T agility test, indicating that from pre-test to post-test the UP had greater improvement than the CON, according to the line graphs. The CVJ and SJ did not differ among types of training or from pre-test to post-test.

Slimani, Chamari, Miarka, Del Vecchio, and Chéour (2016) concluded that more than eight weeks of systematic plyometric training are necessary to improve physical performance in elite players. They also pointed out that shorter period of plyometric training (less than eight weeks) had the potential to enhance a wide range of athletic performance like jumping, sprinting, and agility in children and youth amateur players. Therefore the intervention period of present study was set as eight weeks for the young volleyball players.

Makaruk et al. (2011) studied the effects of unilateral and bilateral plyometric training on power and jumping ability in women and suggested that unilateral plyometric exercises enhanced power and jumping performance in a shorter period compared to the bilateral plyometric exercises that the gains in performance would last longer. In the current study, the plyometrics training programs involved the same number of contacts with the ground between groups (bilateral and unilateral). The current study lasted for 8 weeks which was similar to the pre-training to mid-training period of the study by Makaruk et al. (2011). According to the results of current study, 4 out of 7 assessments (CVJ-R, SJ, RBJ, and T agility test) had better results in UP than BP in terms of the percentage change. This may be explained by the finding by Makaruk et al. (2011), as unilateral plyometric training may be more effective during a short-term training cycle.

The researcher hypothesized that the subjects who received unilateral plyometric training would have better performance than bilateral training group on unilateral power test and agility test, while the subjects who received bilateral plyometric training would have better performance than unilateral training group on bilateral power test. Although the results showed that there were no significant differences between groups, there was a potential showing the differences on the level of improvement when interpreting the percentage change from pre-test to post-test for UP and BP.

For the CVJ-R, the UP jumped higher with a 12.38% increase compared to the 6.10% increase in the BP. Through the observation during the study, most of the volleyball players (right-dominant hand) seldom jump by single right leg, as left leg would be used to jump for a two-step fast attack in most situations. During the intervention, the subjects in UP had a lot of right single leg jumps. Therefore the larger extent of improvement on the CVJ-R may be explained because of the neural adaptation and coordination to the plyometric training for power enhancement (de Villarreal et al., 2009).

For the T agility test, the UP ran faster with a 6.01% decrease in the time compared to the 3.00% decrease in the BP. According to Slimani, Chamari, Miarka, Del Vecchio, and Chéour (2016), previous studies investigating the effect of plyometric training on agility t-test have shown an average of 9.7% decrease in agility time, with the range from 2.5% to 23%. The results of present study did match the findings. Slimani et al. (2016) also indicated that the combination of unilateral and bilateral jump training seems to have more advantages than bilateral jump training alone in improving agility performance. For the differences between UP and BP, it may be explained by the characteristic of running and changing of direction. During running, shuffling, and the moment of changing direction, single leg is used to generate the power for moving our body (McCurdy et al., 2005). It is reasonable that the UP performed better after 8 weeks single leg plyometric training.

For the SJ, both training groups did not have significant improvement after the training. This result may be explained by the specificity of the training. Squat jump removed the countermovement (eccentric contraction) part of a vertical jump, while the subjects did always focus on plyometric training with countermovement jumps triggering the SSC. Therefore it was reasonable that both training groups did not have significant improvement in SJ when there was no specific SJ training throughout the eight weeks intervention.

For the CVJ, both training groups did not have significant improvement after the training. Gottlieb, Eliakim, Shalom, Dello-Iacono, and Meckel (2014) reported no significant changes on bounding distance and vertical jump height after six weeks of plyometric jump training for young basketball players. Likewise, Lehnert, Hůlka, Malý, Fohler, and Zahálka (2013) studied the effects of 6 week plyometric training programme on countermovement jump and two step run up jump. However no significant effect was found in the post-test. Slimani, Chamari, Miarka, Del Vecchio, and Chéour (2016) pointed out that these results were probably due to the characteristics of the subject, such as the training level, sport activity, age, gender, and familiarity with plyometric exercises. The result of current study may be explained by the characteristic of a volleyball game. Volleyball players tend to jump bilaterally in a game in usual, such as traditional side spiking and blocking. Therefore, the subjects already performed a lot of bilateral jumps during the regular volleyball training and competition. This may attenuate the effect of the plyometric training as the subjects did always executed the bilateral countermovement vertical jump in addition to the plyometric training program. As a result, little improvement on the CVJ was observed.

Significant interaction effects existed for the CVJ-R, RBJ, and T agility test, indicating that from pre-test to post-test the UP had significant greater improvement than the CON. This implies that unilateral training can obviously improve certain jumping abilities and agility especially the performance involving single leg movement. Therefore, unilateral training should be included if the sports involve much single leg jumping skills.

The results of this study improve the understanding of the effects of different types of plyometric training on jump and agility performance, and can help develop an effective and efficient training program for sport practice and competition. The results suggest that both unilateral and bilateral plyometric training are valuable and should be considered by the strength and conditioning professionals and sports coaches who would like to focus on improving the jump ability and agility performance of the athletes. The results of this study highlight the potential of using both plyometric training methods to improve the vertical and horizontal power-related components as well as the agility performance of volleyball thought to be necessary for success. Besides, the training programs of present study require no specific equipment (only benches are needed), it is very convenient for coaches to implement the programs to a large group of athletes in a school setting.

Plyometric training also plays an important role in injury prevention. Hewett, Stroupe, Nance, and Noyes (1996) examined the effect of a plyometric jump-training program on landing mechanics and lower extremity strength in female high school volleyball players. After the 6-week training, the researchers found that peak landing forces from a volleyball block jump decreased 22% and knee adduction and abduction moments decreased 50%. Moreover, hamstring-to-quadriceps muscle peak torque ratios increased 26% and 13% on the nondominant side and dominant side respectively, which corrected the side-to side imbalances significantly. The researchers concluded that the plyometric training may have a significant effect on knee stabilization and prevention of serious knee injury among female athletes. Mandelbaum et al. (2005) also pointed out that neuromuscular and proprioceptive training reduced anterior cruciate ligament (ACL) injuries in young female athletes. The training program included plyometrics such as forward hops, single-legged hops, vertical jumps and scissors jumps. The results showed that there was 88% decrease in ACL injury in the training group compared to the control group in the first year of intervention and 74% reduction in ACL tears in the training group compared to the control group in the second year. The researchers concluded that a neuromuscular and proprioceptive training program may have a direct benefit in decreasing the number of ACL injuries incurred by female athletes. As a result, by performing plyometric training not only may the athletes enhance sport performance but also have potential to reduce the rate of injury.

A limitation of the study is that it was difficult to determine the accurate intensity of the training without quantitative measurement. Different from strength training that percentage of 1 repetition maximum can be applied, the subjects in present study used the body weight for the plyometric training, therefore the researcher could not manipulate the exact percentage of intensity for each subject. During the intervention, the researcher did ask the subjects to perform each jump with maximal effort in order to minimize this limitation. The probable inconsistent intensity applied among subjects may affect the degree of effect on the performance.

For recommendation for further study, in addition to the jump height and distance measured in the present study, rate of force development (RFD) would be another useful measurement for assessing muscular power of the athletes. Laffaye and Wagner (2013) found that besides peak RFD and concentric RFD, eccentric RFD was also a strong predictor of jumping performance by summarizing the ability of the muscle-tendons system to store efficiently elastic energy and to release elastic energy as well as activating the stretch reflex. Therefore the further study would be more comprehensive and in-depth if the RFD measurement is included.

Apart from RFD, Electromyography (EMG) can also be used to measure the muscle activation in different parts of muscles. Rodacki, Fowler, and Bennett (2002) examined the segmental coordination of vertical jumps under fatigue of the knee extensor and flexor muscles by using EMG assessment. The researchers found that fatiguing the knee flexor muscles did not reduce the height of the jumps while knee extensor fatigue caused the subjects to adjust several variables of the movement in which the performance was reduced. The researchers suggested that the neural input under the fatigued condition did not form an optimal solution and may lead to the decrease in maximal jump height achievement. Therefore adding EMG to assessment may better help understand the effects of training on muscle activation and coordination.

Researchers should also consider the gender of the subjects. Female subjects were included in the present study; however, gender differences may be a factor affecting the results. de Villarreal et al. (2009) stated that men showed higher gains in vertical jump height compared to women because of the higher power output and better coordination. According to Ceroni, Martin, Delhumeau, and Farpour-Lambert (2012), the highly significant difference in vertical jump performance between male and female teenagers appears to start at age 14. Much greater increase in leg length and muscle volume in male than in female were suggested to be the explanation of the differences. Laffaye, Wagner, and Tombleson (2014) pointed out that the relative eccentric rate of force development was 11.6% higher in males than in females, indicating males have a higher capacity to accelerate their body when performing a countermovement vertical jump. The researchers suggested that the lower rate of force development observed in females may be the result of structural differences in the muscles elastic properties, the higher pennation angles in males than in females of the vastus lateralis (15.8° vs. 14.1°) and the gastrocnemius medialis (26° vs. 24.5°), and longer fascicles in the vastus lateralis in men and gastrocnemii in women, which were concluded to affect the jumping performance. Furthermore, Walsh, Böhm, Butterfield, and Santhosam (2007) found that the arm swing plays an important role in jumping performance in men than in women. The study showed that the arm swing allowed an increase of 7 cm (23%) for men and 4 cm (17%)

for women. The researchers suggested that the greater upper-body strength and coordination of men contributed to the arm swing and therefore resulted in a more significant increase in jump height. Therefore, researchers conducting future studies should include gender as a variable of interest. Another recommendation for the research design is the combination of the training modes. In reality, both unilateral and bilateral training would usually be adopted by the coaches. Therefore, researchers could attempt to compare combined training to unilateral and bilateral training in order to find out the better program for improving the performance outcomes.

Conclusion

According to the findings of current study, CVJ-L, CVJ-R, RBJ, SLJ, and T agility test performance increase from pre-test to post-test for both UP and BP, but there are no significant differences between groups. Significant interaction effects are observed for the CVJ-R, RBJ, and T agility test, indicating that from pre-test to post-test the UP has greater improvement than the CON, according to the line graphs. The CVJ and SJ do not differ among types of training or from pre-test to post-test. It can be concluded that both unilateral and bilateral training are effective on improving most of the performance outcomes, but one program is not significantly better than the other in improving the jump ability and agility performance. The results from the current study indicate the effectiveness of unilateral and bilateral plyometric training on lower body power. Increase in lower body power may potentially improve overall volleyball performance by enhancing the jump ability and agility performance.

REFERENCES

Arabatzi, F., Kellis, E., & Villarreal, E. (2010). Vertical jump biomechanics after plyometric, weightlifting, and combined (weightlifting plyometric) training. *Journal of Strength and Conditioning Research*, *24*(9), 2440- 2448.

Aragón, L. F. (2000). Evaluation of four vertical jump tests: Methodology, reliability, validity, and accuracy. *Measurement in physical education and exercise science*, *4*(4), 215-228.

Baechle, T., & Earle, R. (2008). *Essentials of strength training and conditioning*. Champaign, IL: Human Kinetics.

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

Bobbert, M. F., de Graaf, W. W., Jonk, J. N., & Casius, L. R. (2006). Explanation of the bilateral deficit in human vertical squat jumping. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *100*(2), 493-499.

Bogdanis, G. C., Tsoukos, A., Kaloheri, O., Terzis, G., Veligekas, P., & Brown, L. E. (2017). Comparison between Unilateral and Bilateral Plyometric Training on Single and Double Leg Jumping Performance and Strength. *Journal of Strength and Conditioning Research*, doi:10.1519/JSC.0000000000001962

Boraczyński, T., & Urniaż, J. (2008). The effect of plyometric training on strength-speed abilities of basketball players. *Research Yearbook*, *14*(1), 14-19.

Borras, X., Balius, X., Drobnic, F., & Galilea, P. (2011). Vertical jump assessment on volleyball: A follow-up of three seasons of a high-level volleyball team. *Journal of Strength and Conditioning Research, 25*(6), 1686- 1694.

Cappa, D. F., & Behm, D. G. (2011). Training specificity of hurdle vs. countermovement jump training. *The Journal of Strength & Conditioning Research*, *25*(10), 2715-2720.

Carlock, J. M., Smith, S. L., Hartman, M. J., Morris, R. T., Ciroslan, D. A., Pierce, K. C., ... & Stone, M. H. (2004). The relationship between vertical jump power estimates and weightlifting ability: a field-test approach. *The Journal of Strength & Conditioning Research*, *18*(3), 534-539.

Ceroni, D., Martin, X. E., Delhumeau, C., & Farpour-Lambert, N. J. (2012). Bilateral and gender differences during single-legged vertical jump performance in healthy teenagers. *The Journal of Strength & Conditioning Research*, *26*(2), 452-457.

Channell, B. T., & Barfield, J. P. (2008). Effects of olympic and traditional resistance training on vertical jump improvement in high school boys. *Journal of Strength and Conditioning Research*, *22*(5), 1522- 1527.

Chelly, M., Ghenem, M., Abid, K., Hermassi, S., Tabka, Z., & Shephard, R. (2010). Effects of in-season short-term plyometric training program on leg power, jump- and sprint performance of soccer players. *Journal of Strength and Conditioning Research*, *24*(10), 2670-2676.

Cherif, M. S., Chaatani, S., Nejlaoui, O., Gomri, D., & Abdallah, A. (2012). The effect of a combined high-intensity plyometric and speed training program on the running and jumping ability of male handball players. *Asian journal of sports medicine*, *3*(1), 21.

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International journal of sports physiology and performance*, *3*(2), 131.

Delcore, G., Mathieu, W., Salazar, W., & Hernandez, J. (1998). Comparison between one-leg and two-leg plyometric training on vertical jump performance. *Medicine & Science in Sports & Exercise*, *30*(5), 109.

de Villarreal, E. S. S., Kellis, E., Kraemer, W. J., & Izquierdo, M. (2009). Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *The Journal of Strength & Conditioning Research*, *23*(2), 495-506.

Gabbett, T., Georgieff, B., Anderson, S., & Cotton, B. (2006). Changes in skill and physical fitness following training in talent-identified volleyball players. *Journal of Strength and Conditioning Research*, *20*(1), 29.

Gehri, D. J., Ricard, M. D., Kleiner, D. M., & Kirkendall, D. T. (1998). A comparison of plyometric training techniques for improving vertical jump ability and energy production. *Journal of Strength and Conditioning Research*, *12*, 85-89.

Gottlieb, R., Eliakim, A., Shalom, A., Dello-Iacono, A., & Meckel, Y. (2014). Improving anaerobic fitness in young basketball players: Plyometric vs. specific sprint training. *Journal of Athletic Enhancement*, *3*(3).

Hewett, T. E., Stroupe, A. L., Nance, T. A., & Noyes, F. R. (1996). Plyometric training in female athletes: decreased impact forces and increased hamstring torques. *The American journal of sports medicine*, *24*(6), 765-773.

Hori, N., Newton, R. U., & Nosaka, K. (2005). Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength and Conditioning Journal, 27*(4), 50-55.

Isaacs, L. D. (1998). Comparison of the Vertec and Just Jump systems for measuring height of vertical jump by young children. *Perception Motor Skills, 86*(2), 659- 663.

Jensen, J. L., & Russell, P. J. (1985). Depth jump training and the volleyball spike. *International Symposium* on *Biomechanics in Sports*, 304-313.

Johnson, B. A., Salzberg, C. L., & Stevenson, D. A. (2011). A systematic review: plyometric training programs for young children. *The Journal of Strength & Conditioning Research, 25*(9), 2623-2633.

Jones, M. T., Ambegaonkar, J. P., Nindi, B. C., Smith, J. A., & Headley, S. A. (2012). Effects of unilateral and bilateral lower-body heavy resistance exercise on muscle activity and testosterone responses. *Journal of Strength and Conditioning Research, 26*(4), 1094-1100.

Katić, R., Grgantov, Z., & Jurko, D. (2006). Motor structures in female volleyball players aged 14–17 according to technique quality and performance. *Collegium antropologicum, 30*(1), 103-112.

Kenny, I. C., Caireallain, A. O., & Comyns, T. M. (2012). Validation of an electronic jump mat to assess stretch-shortening cycle function. *Journal of Strength and Conditioning Research, 26*(6), 1601-1608.

Laffaye, G., & Wagner, P. (2013). Eccentric rate of force development determines jumping performance. *Computer methods in biomechanics and biomedical* *engineering*, *16*(sup1), 82-83.

Laffaye, G., Wagner, P. P., & Tombleson, T. I. (2014). Countermovement jump height: Gender and sport-specific differences in the force-time variables. *The Journal of Strength & Conditioning Research*, *28*(4), 1096-1105.

Leard, J., Cirillo, M., Katsnelson, E., Kimiatek, D., Miller, T., Trebincevic, K., & Garbalosa, J. (2007). Validity of two alternative systems for measuring vertical jump height. *Journal of Strength and Conditioning Research*, *21*(4), 1296-1299.

Lehnert, M., Hůlka, K., Malý, T., Fohler, J., & Zahálka, F. (2013). The effects of a 6 week plyometric training programme on explosive strength and agility in professional basketball players. *Acta Gymnica*, *43*(4), 7-15.

Lehnert, M., Lamrova, I., & Elfmark, M. (2009). Changes in speed and strength in female volleyball players during and after a plyometric training program. *Acta Universitatis Palackianae Olomucensis Gymnica, 39(1),* 59-66.

Lockie, R., Murphy, A., Schultz, A., Knight, T., & Janse de Jonge, X. (2012). The effects of different speed training protocols on sprint acceleration kinematics and muscle strength and power in field sport athletes. *Journal of Strength and Conditioning Research, 26(6),* 1539-1550.

Lorger, M., Hraski, M., & Hraski, Ž. (2012). The effects of motor learning on results of standing long jump performed by female students. *Sport Science*, *5*(1), 27-31.

Makaruk, H., Winchester, J. B., Sadowski, J., Czaplicki, A., & Sacewicz, T. (2011). Effects of unilateral and bilateral plyometric training on power and jumping ability in women. *The Journal of Strength & Conditioning Research*, *25*(12), 3311-3318.

Mandelbaum, B. R., Silvers, H. J., Watanabe, D. S., Knarr, J. F., Thomas, S. D., Griffin, L. Y., ... & Garrett, W. (2005). Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes. *The American journal of sports medicine*, *33*(7), 1003-1010.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal* of *Strength and Conditioning Research, 8*(3), 551-555.

May, C. A., Cipriani, D., & Lorenz, K. A. (2010). Power development through complex training for the division 1 collegiate athlete. *Strength and Conditioning Journal, 32*(4), 30-43.

McClenton, L. S., Brown, L. E., Coburn, J. W., & Kersey, R. D. (2008). The effect of short-term vertimax vs. depth jump training on vertical jump performance. *Journal* of *Strength and Conditioning Research, 22*(2), 321-325.

McCurdy, K. W., Langford, G. A., Doscher, M. W., Wiley, L. P., & Mallard, K. G. (2005). The effects of short-term unilateral and bilateral lower-body resistance training on measures of strength and power. *The Journal of Strength & Conditioning Research*, *19*(1), 9-15.

Miller, M. G., Herniman, J. J., Ricard, M. D., Cheatham, C. C., & Michael, T. J. (2006). The effects of a 6-week plyometric training program on agility. *Journal of Sports Science and Medicine*, *5*(3), 459-465.

Peterson, M., Alvar, B., & Rhea, M. (2006). The contribution of maximal force production to explosive movement among young collegiate athletes. *Journal of Strength and Conditioning Research, 20*(4), 867-873.

Powers, M. E. (1996). Vertical Jump Training for Volleyball. *Strength & Conditioning Journal*, *18*(1), 18-23.

Ramírez-Campillo, R., Burgos, C. H., Henríquez-Olguín, C., Andrade, D. C., Martínez, C., Álvarez, C., ... & Izquierdo, M. (2015). Effect of unilateral, bilateral, and combined plyometric training on explosive and endurance performance of young soccer players. *The Journal of Strength &*

Conditioning Research, *29*(5), 1317-1328.

Ramirez-Campillo, R., Sanchez-Sanchez, J., Gonzalo-Skok, O., Rodríguez-Fernandez, A., Carretero, M., & Nakamura, F. Y. (2018). Specific Changes in Young Soccer Player's Fitness After Traditional Bilateral vs. Unilateral Combined Strength and Plyometric Training. *Frontiers In Physiology*, *9*265. doi:10.3389/fphys.2018.00265

Rodacki, A. L. F., Fowler, N. E., & Bennett, S. J. (2002). Vertical jump coordination: fatigue effects. *Medicine & Science in sports & exercise*, *34*(1), 105-116.

Sattler, T., Sekulic, D., Hadzic, V., Uljevic, O., & Dervisevic, E. (2012). Vertical jumping tests in volleyball: Reliability, validity and playing-position specifics. *Journal of Strength and Conditioning Research*, *26*(6), 1532-1538.

Sheppard, J. M., Cronin, J. B., Gabbett, T. J., McGuigan, M. R., Etxebarria, N., & Newton, R. U. (2008). Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. *Journal* of *Strength and Conditioning Research*, *22*(3), 758-765.

Slimani, M., Chamari, K., Miarka, B., Del Vecchio, F. B., & Chéour, F. (2016). Effects of Plyometric Training on Physical Fitness in Team Sport Athletes:

A Systematic Review. *Journal Of Human Kinetics*, *53*(1), 231-247.

Turner, A. N., & Jeffreys, I. (2010). The stretch shortening cycle: Proposed mechanisms and methods for enhancement. *Strength and Conditioning Journal, 32(4)*, 87-99.

Turner, A. M., Owings, M., & Schwane, J. A. (2003). Improvement in running economy after 6 weeks of plyometric training. *The Journal of Strength & Conditioning Research*, *17*(1), 60-67.

Veligekas, P., Tsoukos, A., & Bogdanis, G. C. (2012). Determinants of standing long jump performance in 9-12 year old children. *Serbian Journal of Sports Sciences*, *6*(4), 147-155.

Verkhoshansky, Y. (l968). Are depth jumps useful? *Review Soviet Physical Education Sports*, *4*, 75-78.

Voelzke, M., Stutzig, N., Thorhauer, H., & Granacher, U. (2012). Promoting lower extremity strength in elite volleyball players: Effects on two combine training methods. *Journal* of *Science and Medicine* in *Sport*, 1- 6.

Walsh, S., Böhm, H., Butterfield, M., & Santhosam, J. (2007). Gender bias in the effects of arms and countermovement on jumping performance. *Journal of strength and conditioning research*, *21*(2), 362.

Wilson, J. M., & Flanagan, E. P. (2008). The role of elastic energy in activities with high force and power requirements: a brief review. *The Journal of Strength & Conditioning Research*, *22*(5), 1705-1715.

Wisloff, D., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, *38*, 285-288.

Appendix A

INFORMED CONSENT

Explanation of the tests

The intervention period will last for 8 weeks. During the study, you will be instructed not to perform any other strength or plyometric training that might influence the results. Pre-test and post-test will be performed immediately before and 3-5 days after the intervention period. Assessment includes bilateral countermovement vertical jump, unilateral countermovement vertical jump (left leg and right leg), squat jump, 5 repeated block jumps, standing long jump, and T agility test. For the experimental groups, you will complete 15 unilateral or bilateral plyometric training sessions over 8 weeks in addition to the regular volleyball training. For the control group, you will perform the regular volleyball training only. you will be trained two sessions a week and the sessions will be at least 48 hrs apart. At least one certified strength and conditioning specialist will lead the sessions and supervise all the subjects with careful attention to proper exercise techniques. All plyometric training sessions will be performed at the end of each regular volleyball training session. Each plyometric training session will take approximately 30 min. Plyometric training for the unilateral group includes single leg exercises only and plyometric training for the bilateral group includes double leg exercises only, both with a progression in intensity and volume.

Risks and discomforts

The possible risks involved with participation in this investigation are delayed onset muscle soreness, elevated heart rate, lower back injuries, muscle strain, or upper and lower body injuries. To minimize these risks you will be required to follow the safety guidelines laid out by the instructor.

All warm-up techniques, testing and training will be performed under the supervision of an instructor who is both Certified Strength and Conditioning Specialist and CPR/AED certified. Should a physical injury occur, appropriate first aid will be provided.

Expected benefits from testing and training

The tests allow us to assess your physical working capacity and to appraise your physical fitness status. You may enhance your jump ability and agility performance by completing the training program. All records are kept strictly confidential unless you consent to release this information.

Inquiries

Questions about the procedures used in the physical fitness test and the training program are encouraged. If you have any questions or need additional information, please ask us to explain further.

Freedom of Consent

Your permission to perform these physical fitness tests and training program is strictly voluntary. You are free to stop the tests or training at any point, if you so desire.

I have read this form carefully and I fully understand the test procedures and training that I will perform and the risks and discomforts. Knowing these risks and having had the opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this study.

Date: __________________ Signature of subject: _____________________

Date: __________________ Signature of witness: ____________________

Appendix B

INDIVIDUAL RECORDING SHEET

Name: _______________ Group: _____ Dominant hand: _____

Age: __________ Weight: __________ Height: ________

CMVJ: **Pre:** Trial 1__________ Trial 2__________

Post: Trial 1__________ Trial 2__________

CMVJ (L): **Pre:** Trial 1__________ Trial 2__________

Post: Trial 1__________ Trial 2__________

CMVJ (R): **Pre:** Trial 1__________ Trial 2__________

Post: Trial 1__________ Trial 2__________

Squat Jump: **Pre:** Trial 1_________ Trial 2_________

Post: Trial 1_________ Trial 2_________

5 Repeated Block Jumps: Pre: Trial 1__ __ __ ___ ___

Post: Trial 1__ ___ ___ ___ ___

LJ: **Pre:** Trial 1________ Trial 2________ Trial 3_______

Post: Trial 1________ Trial 2________ Trial 3_______

T Agility Test:

Pre: Trial 1_________ Post: Trial 1_________

Appendix C

PLYOMETRIC TRAINING PROGRAM

Bilateral plyometric training group

Day 1 Bilateral Training

Exercises	Sets	Reps	Rest between sets
Air squat to parallel	For proper technique		
Heels off to drop squat	3	8	1 min
Squat jump (hold squat position for 2s)	3	6	1 min
Ankle hop	3	15	1 min
Broad jump stick land (2s)	3	5	1 min
Side to side jump	3	16	1 min
Air squat to parallel	1	20 (4s eccentric)	

Day 2 Bilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Heels off to drop squat	3	8	1 min
Continuous squat jump (hands touch ground)	3	6	1 min
90° ankle hop (3 directions: left,	3	15	1 min

front, right)			
Front to back jump	3	20	1 min
Vertical jump followed by a bounce	3	6	1 min
Air squat to parallel	1	20 (4s eccentric)	

Day 3 and 4 Bilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Continuous squat jump (hands touch ground)	4	6	1 min
Ankle hop	4	15	1 min
Step and vertical jump	4	6	1 min
Cone forward jump stick land	4	6	1 min
Air squat to parallel	1	20	

Day 5 and 6 Bilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Tuck jump	4	6	1 min
Split squat jump	4	6	1 min
Step and vertical jump	4	6	1 min

Cone forward jump	4	6	1 min
Air squat to parallel + heels raise	1	20	

Day 7 and 8 Bilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Continuous Vertical jump	4	6	1 min
Cycled split squat jump	4	6	1 min
Zig zag bound (stick land)	4	8	1 min
Vertical jump 90° (left, front, right)	4	6	1 min
Air squat + heels raise	1	20	

Day 9 and 10 Bilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Board jump + Vertical jump	4	6	1 min
Cycled split squat jump	4	6	1 min
Zig zag bound	4	8	1 min
Vertical jump 180°	4	6	1 min
Air squat + heels raise	1	20	

Day 11 and 12 Bilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Board jump + Vertical jump (Continuous)	4	8 jumps in total	1 min
Drop vertical jump from bench	4	6	1 min
Zig zag bound	4	8	1 min
Vertical jump 180°	4	6	1 min
Air squat parallel hold	1	30s	

Day 13 and 14 Bilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Step and vertical jump	4	6	1 min
Drop vertical jump from bench	4	6	1 min
Bench jumping up and down	4	8	1 min
Vertical jump 180°	4	6	1 min
Air squat parallel hold	1	30s	

Day 15 Bilateral Training

Exercises	Sets	Reps	Rest between sets

Squat (Warm up)	1	10	
Step and vertical jump	4	6	1 min
Drop board jump from bench	4	6	1 min
Continuous bench drop jumps (4 benches in a row)	4	8	1 min
Forward hopping	4	6	1 min
Air squat parallel hold	1	30s	

Unilateral plyometric training group

Day 1 Unilateral Training (same with bilateral group)

Exercises	Sets	Reps	Rest between sets
Air squat to parallel	For proper technique		
Heels off to drop squat	3	8	1 min
Squat jump (hold squat position for 2s)	3	6	1 min
Ankle hop	3	15	1 min
Broad jump stick land (2s)	3	5	1 min
Side to side jump	3	16	1 min
Air squat to parallel	1	20 (4s eccentric)	

Day 2 Unilateral Training (same with bilateral group)

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Heels off to drop squat	3	8	1 min
Continuous squat jump (hands touch ground)	3	6	1 min
90° ankle hop (3 directions: left, front, right)	3	15	1 min
Front to back jump	3	20	1 min
Vertical jump followed by a bounce	3	6	1 min
Air squat to parallel	1	20 (4s eccentric)	

Day 3 and 4 Unilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Single leg continuous squat jump (one hand touch ground) (Land with both feet)	2 sets each	6	1 min
Single leg vertical ankle hop	2 sets each	15	1 min
Step and single leg vertical jump (Land with both feet)	2 sets each	6	1 min
Single leg board	2 sets each	6	1 min

jump stick land with both feet			
Split squat	1 set each	10	

Day 5 and 6 Unilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Tuck jump	4	6	1 min
Split squat jump (front leg jumps and lands first)	2 sets each	6	1 min
Step and single leg vertical jump (Land with both feet)	2 sets each	6	1 min
Single leg hop	2 sets each	6	1 min
Split squat + heel raise	1 sets each	10	

Day 7 and 8 Unilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Single leg vertical jump	2 sets each	6	1 min
Cycled Split squat jump	2 sets each	6	1 min
Single leg zig zag bound stick land	4	8	1 min
Single leg 90° jump	2 sets each	6	1 min
Split squat + heel	1 sets each	10	

raise			

Day 9 and 10 Unilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Single leg board jump + both leg vertical jump	2 set each	6	1 min
Cycled split squat jump	2 set each	6	1 min
Single leg zig zag bound	4	8	1 min
Single leg vertical jump 180° (inward)	2 set each	6	1 min
Split squat + heel raise	1 set each	10	

Day 11 and 12 Unilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Single leg alternative vertical jump (left leg jumps right leg lands and vice versa)	4	8	1 min
Drop vertical jump from bench (land with both leg and jump with single leg)	2 set each	6	1 min
Single leg zig zag	4	8	1 min

bound			
Single leg vertical jump 180° (inward)	2 set each	6	1 min
Split squat parallel hold	1 set each	15s	

Day 13 and 14 Unilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Step and single leg vertical jump (Land with single leg)	2 set each	6	1 min
Drop vertical jump from bench (land and jump with single leg)	2 set each	6	1 min
Bench single leg jumping up and down	2 set each	8	1 min
Single leg vertical jump 180° (inward)	2 set each	6	1 min
Split squat parallel hold	1 set each	15s	

Day 15 Unilateral Training

Exercises	Sets	Reps	Rest between sets
Squat (Warm up)	1	10	
Step and single leg vertical jump (Land with single	2 set each	6	1 min

leg)			
Drop single leg board jump from bench	2 set each	6	1 min
Continuous bench single leg drop jumps (4 benches in a row)	2 set each	8	1 min
Forward single leg hopping	2 set each	6	1 min
Split squat parallel hold	1 set each	15s	

Appendix D

STATISTICS TABLES

Table 1

3 X 2 Mixed Factorial ANOVA Comparing CVJ Before and After 8 Weeks

Source	*SS*	*df*	*MS*	*F*	*p*
Between Groups					
Group (B)	98.19	2	49.10	1.01	.37
Error	2882.40	59	48.85		
Within Subjects					
Occasion (A)	6.15	1	6.15	1.53	.22
A X B	18.12	2	9.06	2.26	.11
Error	236.69	59	4.01		

Table 2

3 X 2 Mixed Factorial ANOVA Comparing CVJ-L Before and After 8 Weeks

Source	*SS*	*df*	*MS*	*F*	*p*
Between Groups					
Group (B)	62.11	2	31.06	1.36	.27
Error	1347.34	59	22.84		
Within Subjects					
Occasion (A)	83.80	1	83.80	25.86	.00
A X B	10.55	2	5.28	1.63	.21
Error	191.20	59	3.24		

Table 3

3 X 2 Mixed Factorial ANOVA Comparing CVJ-R Before and After 8 Weeks

Source	*SS*	*df*	*MS*	*F*	*p*
Between Groups					
Group (B)	74.38	2	37.19	1.62	.21
Error	1353.41	59	22.94		
Within Subjects					
Occasion (A)	46.38	1	46.38	12.79	.00
A X B	27.66	2	13.83	3.81	.03
Error	213.98	59	3.63		

Table 4

3 X 2 Mixed Factorial ANOVA Comparing SJ Before and After 8 Weeks

Source	*SS*	*df*	*MS*	*F*	*p*
Between Groups					
Group (B)	78.32	2	39.16	0.70	.50
Error	3317.22	59	56.22		
Within Subjects					
Occasion (A)	9.21	1	9.21	2.19	.14
A X B	11.82	2	5.91	1.41	.25
Error	247.88	59	4.20		

Table 5

3 X 2 Mixed Factorial ANOVA Comparing RBJ Before and After 8 Weeks

Source	*SS*	*df*	*MS*	*F*	*p*
Between Groups					
Group (B)	41.33	2	20.66	0.51	.60
Error	2399.55	59	40.67		
Within Subjects					
Occasion (A)	37.25	1	37.25	14.43	.00
A X B	20.75	2	10.38	4.02	.02
Error	152.29	59	2.58		

Table 6

3 X 2 Mixed Factorial ANOVA Comparing SLJ Before and After 8 Weeks

Source	*SS*	*df*	*MS*	*F*	*p*
Between Groups					
Group (B)	958.82	2	479.41	0.64	.53
Error	44281.86	59	750.54		
Within Subjects					
Occasion (A)	1350.77	1	1350.77	25.44	.00
A X B	182.94	2	91.47	1.72	.19
Error	3132.93	59	53.10		

Table 7

3 X 2 Mixed Factorial ANOVA Comparing T agility test Before and After 8 Weeks

Source	*SS*	*df*	*MS*	*F*	*p*
Between Groups					
Group (B)	4.42	2	2.21	1.13	.33
Error	114.82	59	1.95		
Within Subjects					
Occasion (A)	8.55	1	8.55	40.09	.00
A X B	1.76	2	0.88	4.12	.02
Error	12.58	59	0.21		

CURRICULUM VITAE

Academic qualifications of the thesis author, Mr. KONG Tsz Yeung:

- Received the degree of Bachelor of Arts (Honours) from Hong Kong Baptist University, November 2012.
- Received the degree of Master of Science from Springfield College, USA, December 2014.

June 2018