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The Relationship of Strength and Body Composition to Vertical Jump Ability in Division 1 Female Volleyball Players.

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Abstract

The Relationship of Strength and Body Composition to Vertical Jump Ability in Division 1 Female Volleyball Players

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Jump ability is important in volleyball; therefore analysis of factors that influence jump performance is necessary to ensure maximal jump ability. **Purpose:** To analyze how strength characteristics associated with jumping are affected by percent body fat, lean body mass and free fat mass. **Methods:** Data from eleven female NCAA DI volleyball players as part of an ongoing athlete monitoring program collected from 2007-2010 was analyzed. Data was separated into weakest and strongest based on isometric peak force allometrically scaled. In all cases the weakest data corresponded to testing during the athletes first year at ETSU. Body composition was measured using air displacement plethsmography (BodPod). Maximum strength (isometric peak force – IPF) and strength characteristics (peak force -F@ 50ms, 90ms, and 250ms; rate of force development, 0-200ms –RFD) were measured with isometric mid-thigh pulls on a force plate, and countermovement jumps with 0, 11 and 20 kg . Allometric scaling of the different force values (IPFa, F@50a, F@90a, F@250a) was used to normalize differences in the body mass of the athletes (absolute force/ (body mass ($kg^{0.67}$)). Pearson correlations were used to determine the relationship strengths. **Results:** In weaker test results, there are moderate and small inverse correlations between CMJ and PF (r=-0.34) and PFa (r= -0.19), and strong inverse correlations between CMJ and percent body fat (r=-0.67). In stronger test results there are small correlations between CMJ and PF (r=0.23), PFa (r= 0.26), and moderate inverse correlations between CMJ and percent body fat (r=-0.40). There is a significant change in jump ability and strength between both groups. **Conclusion:** As an athlete becomes stronger, there is a significant correlation between CMJ strength, PF, PFa, F250, and F250a. The relationship between CMJ and strength characteristics decreases as BF increases.

Introduction

Resistance training has important impact on the success of males and females in many sports. However, a female athlete's commitment to strength and conditioning programs can be influenced by the fear of developing a masculine build (Swedan, 2001). Resistance training in females will not cause an increase in muscle size to the same extent as in males (Lydiard & Gilmour, 2000) due to testosterone levels being lower in women than men (Lippa, 2005). Testosterone stimulates muscle hypertrophy by stimulating the secretion of growth hormone, and stimulating protein synthesis, both in response to resistance training(Vander, Sherman, & Luciano, 2001) (Rhoades & Bell, 2009) and without resistance training (Pearl, 2001). Therefore, women rarely experience severe muscular development from weight training unless anabolic steroids are being used (Pearl, 2001). However, it has been noted that better volleyball players are older, stronger, larger, and are able to jump higher (Fry, et al., 1991).

The ability to quickly and forcefully use strength is essential in jumping. The amount of work done per unit of time produced by a muscle is represented as power. Improved performance cannot be achieved without an increase in power (Adams, O'Shea, O'Shea, & Climstein, 1992). The ability of an athlete to obtain a high vertical jump (VJ) quickly is critical for success in volleyball (Powers 1996). The sport uses jumping during the jump set, jump serve, block and spike. To be successful in these tasks, a player must be able to not only jump high, but also reach that height quickly. To increase athletic performance, and therefore obtain the demands of the sport, it is necessary to not only increase strength, but also increase speed (Powers 1996). Increasing speed, strength, and power can be achieved through training based around fast, explosive movements. Through neuromuscular adaptation, the rate of force development in type II muscle fibers can be enhanced through explosive training. Theoretically, this would reduce the movement time during a jump (Tant, Lamack, & Greene, 1993), therefore, explosive training should increase the amount of power produced (Powers 1996). Resistance training has also shown to improve jump ability in athletes (Fry, et al., 1991). In women, peak power is most closely associated to vertical jump (VJ) performance. The quantity and efficiency in the development of force produced through the hip, knee, and ankle determine jump performance (Ashley & Weiss, 1994). Therefore, is could be beneficial to examine the forces produced through the lower body in athletes.

Body composition is a factor often examined as it relates to female athletes and athletic performance. However, there are some arguments as to why body composition should be a major focus of training. It is a common fallacy that continued weight loss will ensure improvements in athletic performance (Wilmore, Bownell, Rodin, & Wilmore, 1992). Another reason why body composition should not be overemphasized is that methods of measuring body composition may not be precise, and therefore, can give inaccurate data. While increases in fat mass can have negative effects on sport performance(Rickenlund, Carlstrom, Ekblom, Brismar, Von Schoultz, & Linden Hirschberg, 2004) following body composition measures too closely and holding an athlete to a standard for body fat percentage can have serious consequences, including the female athlete triad (Yeager, Agostini, Nattiv, & Drinkwater, 1993). The female athlete triad is comprised of anorexia, amenorrhea, and osteoporosis. This disorder is listed as being more prevalent in athletes than non athletes, as well as more prevalent in female sports that involve prominence on low body fat (Sundgot-Borgen & Torstveit, 2005). The presence of the triad increases the risk of morbidity, as well as greatly increases the risk of mortality (Sundgot-Borgen & Torstveit, 2005). While a diet and conditioning program's primary goal may be fat loss, muscle mass can be lost as well which can lead to deteriorating performance. Extreme caloric restriction can cause maximal weight loss and lead to fatigue, anemia, electrolyte abnormalities and depression. All of these factors can negatively affect athletic performance (Yeager, Agostini, Nattiv, & Drinkwater, 1993).

The body composition of a female athlete as well as the ability of the athlete to perform a vertical jump has a large impact on the performance of the athlete. It is ideal for the athlete to improve in strength as training progresses. Therefore, the purpose of this study is to analyze the relationship between vertical jump performance and body composition as the athlete becomes stronger.

Operational Definitions

1. Countermovement jump (CMJ): A vertical jump that is preceded by a rapid stretch-shorten or pre-stretch cycle. This type of jump provides information on an individual's ability to utilize the stretch shortening cycle.
2. Flight Time: The point in which the individual leaves the force plate to the point in which contact is regained (i.e. time in the air).
3. Jump Height (JH): Derived from flight time. It is an estimate of the total vertical displacement of the individual's center of mass during a vertical jump.
4. Explosive strength: The ability for an individual to rapidly produce force. Often measured with the vertical jump or rate of force development during an isometric mid-thigh clean pull.
5. Isometric Mid-Thigh Clean Pull: A method of measuring strength. Isometric force is generated while an individual stands on a force plate while pushing vertically downward on the force plate and pulling up an immovable bar. The subject is placed in a position with the angle of the knee between 120°-130°, and the position of the hip between 170°-180° (i.e. trunk is upright).
6. Isometric force characteristics: Measures of strength obtained during an isometric mid-thigh clean pull.

a. Isometric Peak Force (IPF): The highest positive value achieved during an isometric mid-thigh clean pull. Measured in Newton's.

b. Isometric Rate of Force Development (IRFD): A measure of explosive strength during an isometric mid-thigh clean pull, measured beginning at the onset of the pull and ending at 200ms. Measured in Newton x s^{-1}.

c. Instantaneous Force (IF): Force measured at a specified time during the isometric pull. Examples include Force at 50, 90, and 250 ms.

7. Stretch-shortening cycle: The combination of eccentric and concentric muscle actions. A type of action in which an eccentric phase or action immediately precedes the concentric phase of movement.

Review of Literature

Athletic performance is an area of increasing research. A variety of factors influence improvements in performance, and studying these factors has a large impact on the ability of athletes to gain strength characteristics. Initial increases in strength characteristics are products of increased neural adaptation (Hamill & Knutzen 2009). The stretch-shortening cycle (SSC), maximal force and power output, and rate of force development are several factors influencing the ability of an athlete to increase performance. The stretch-shortening cycle (SSC) is a series of lengthening and shortening of the muscles as an athlete begins a vertical jump (Komi, Strength and Power in Sport, 2003). The first phase, the lengthening phases, puts the muscle on a stretch and stores a large amount of potential energy to be used in the following phase, which is the shortening phase (Komi, Strength and Power in Sport, 2003). This cycle allows a maximum amount of explosive power to be produced through the jump. Plyometrics is a form of conditioning that trainers use to harness and improve this explosive power (Kraemer & Newton, 1994). In plyometric training, increased muscle tension allows power output to be increased (Hamill & Knutzen 2009). Ballistic power training and heavy strength training are also used to target increases in power output (Cormie, McGuigan, & Newton, Adaptations in Athletic Performance after Ballistic Power versus Strength Training, 2010). It is suggested to include not only ballistic training, but plyometric depth training to elicit improvements in vertical jump (Gehri, Ricard, Kleiner, & Kirkendall, 1998). A major distinguishing factor between athletes is their ability to generate a considerable amount of power. The highest possible power generated in a performance can occur once force and velocity are at optimum values; this is known as peak power (PP) (Stone, O'Bryant, McCoy, Coglianese, Lehmkuhl, & Schilling, 2003). Maximum strength is a basic unit of power output (Stone, O'Bryant, McCoy, Coglianese, Lehmkuhl, & Schilling, 2003); it can therefore be assumed that by achieving maximum strength, the highest possible power output will also be achieved. Athletic trainers often make intuitive leaps, and assume that larger athletes require more energy and power than their lighter counterparts. Often, it becomes theorized that lighter athletes would be able to jump higher than a heavier athlete, and therefore, decreased the amount of strength training done (Kraemer & Newton, 1994). However, Ashley et al found no relationship between jump performance and body weight (Ashley & Weiss, 1994) and Weiss et al found a negative relationship between the peak force and percent body fat (Weiss, Relyea, Ashley, & Propst, 1997).

Volleyball uses a multitude of movements. A crucial one being a countermovement jump (CMJ). A counter movement jump is characterized by a beginning in erect positioning, followed by a downward movement, then a push off (Bobbert, Gerristen, Litjens, & Van Soest, 1996). This movement is typically done because the participant is able to achieve the highest jump by allowing the muscle to build up an active state. At the beginning of countermovement, the muscle is said to be in a pre-stretch, which allows for maximum energy absorption, which is temporarily absorbed in the series elastic elements in the muscle; as time elapses with the held pre-stretch, the energy potential decreases. As the muscle stimulation increases during the pre-stretch, the ability to produce a larger force increases, which also leads to an increase in work done during this concentric movement (Bobbert, Gerristen, Litjens, & Van Soest, 1996). However, if the stretch is held for too long, the potential energy will be lost.

A large component of the countermovement jump is the stretch-shortening cycle (SSC) which occurs during the countermovement (Komi, Stretch-Shortening Cycle: A Powerful Model t Study Normal and Fatigued Muscle, 2000). The stretch-shortening cycle is composed of two phases: lengthening and shortening. The lengthening phase acts eccentrically (Komi, Strength and Power in Sport, 2003); during this phase, the active muscle is forcibly stretched, which produces a large amount of potential energy which is stored to be later used in the next phase (Komi, Strength and Power in Sport, 2003) and very little electromyogram activity (Finni, Komi, & Lepola, 2000). The shortening phase acts concentrically (Komi, Strength and Power in Sport, 2003), and produces the greatest work (Kawakami, Muraoka, Ito, Kanehisa, & Fukunaga, 2002). These two phases complete important aspects of the stretch-shortening cycle: preactivation, and activation of the muscle following the phases of the movement. The purpose of SSC is to obtain an enhancement of performance during the concentric phase, compared to a static jump. Many studies have been conducted monitoring the work output conducted by SSC. Finni et al studied the triceps surae and the quadriceps femoris muscles and their function in a CMJ. They found that tendon undergoes a SSC, and thus, has the prospective for elastic energy storage and utilization (Finni, Komi, & Lepola, 2000). Pretension generated isometrically as opposed to an active stretch can generate significantly greater work output during the first 500 ms of the shortening phase after a pre-stretch (Walshe, Wilson, & Ettema, 1998). When the muscle fibers during a SSC movement are minimally displaced, the fibers operate at almost optimal length and can therefore produce more force. In the eccentric phase of SSC movements, the muscle spindles become mechanically deformed, which activates reflex mechanisms. This then causes the stretch reflex to increase muscle stimulation. This results in an increased contraction force in the concentric phase, ultimately contributing to enhanced maximal power output (Cormie, McGuigan, & Newton, Influence of Strength on Magnitude and Mechanisms of Adaptation to Power Training, 2010). Avela et al examined various activities that created a reduced SSC reflex sensitivity. They found that a prolonging SSC exercises can result in reduction in performance (Avela & Komi, Reduced Stretch reflex Sensitivity and Muscle Stiffness after Long-Lasting Stretch-shortening cycle exercise in humans, 1998).

Most sports encompass explosive force to accelerate the body in a given direction (Kraemer & Newton, 1994). Athletic performance is often assessed by the strength and power of the athlete (Brown & Weir, 2001), and because of this, athletic coaches often focus on strength building exercises. Plyometrics and ballistic power training are two popular strength and power building exercises. Plyometrics puts the muscle on a quick prestretch, followed by a concentric muscle action leads to maximum facilitation; the purpose is improving velocity and power output during athletic performance

(Hamill & Knutzen 2009). Plyometrics improves power output through facilitation of neurological input and through increased muscle tension. The type 1a sensory neuron is utilized through the stretch reflex and forms the basis for neurological input. The rapid stretching excites alpha motoneurons which increase with the velocity of the stretch (Hamill & Knutzen 2009). The restitution of elastic energy accounts for most of the increases in output due to plyometrics training (Avela, Kyrolainen, Komi, & Rama, 1999). During the eccentric action of the muscle, elastic potential energy is stored in the connective tissue; as long as the stretch is short term, there is maximal recovery of the stored elastic potential energy, and is then used during the contraction of the muscle. Because of the vigorous eccentric actions done during plyometrics, focus should be on the number of exercises, and the load imposed. It is suggested that plyometrics be done on a level surface, and be done no more than two days a week. It is also recommended that strength base exercises should be induced before the beginning of plyometrics training to reduce the risk of injury (Hamill & Knutzen 2009). Examples of plyometric exercises include: single leg bounds, depth jumps, use of surgical tubing and medicine balls.

Ballistic power training and heavy strength training are commonly used to bring about significant improvements in athletic performance and target improvements in power output (Cormie, McGuigan, & Newton, Adaptations in Athletic Performance after Ballistic Power versus Strength Training, 2010). Ballistic power training focuses on explosive movements, which leads to an increase in strength. Naturally, there are biomechanical sticking points in which the use of one muscle group transitions to the next. Ballistic training uses explosive movements to push past the sticking points. Ballistic training focuses on acceleration, and forces your body to use fast-twitch muscle fibers. These fibers have the greatest potential for strength improvements, and because the ballistic movements force high power output, the fast-twitch fibers are trained to respond with increased strength output. It is recommended that ballistic exercises use 30 to 50 percent of the 1RM for that exercise because this is when optimal power is produced. Three to five repetition maximum should be used for all ballistic exercises to prevent fatigue, and reach maximal effort at each repetition. To prevent fatigue, it is suggested to take three minute breaks between repetitions (Stoppani, 2006). Common ballistic exercises are bench press throws and jump squats. Ballistic power training has been proven throughout literature to bring about improvements in athletic performance and often increase maximal power output, rate of force development, movement velocity, jump height, and sprint performance (Cormie, McGuigan, & Newton, Adaptations in Athletic Performance after Ballistic Power versus Strength Training, 2010). Ballistics training and strength training have both proven to elicit improvements in athletic performance even after short-term exposure when coupled with sports-specific movements (Cormie, McGuigan, & Newton, Adaptations in Athletic Performance after Ballistic Power versus Strength Training, 2010). Focusing on sports-specific movements, ballistics power training increases the rate of EMG rise during jumping, which helps to optimize the functions of SSC (Cormie, McGuigan, & Newton, Adaptations in Athletic Performance after Ballistic Power versus Strength Training, 2010). Through this power training, subjects are able to achieve greater acceleration and movement velocity in shorter periods, therefore, increasing athletic performance (Cormie, McGuigan, & Newton, Adaptations in Athletic Performance after Ballistic Power versus Strength Training, 2010).

While ballistic training is heavily studied, some suggest other approaches to improving athletic performance. Gehri et al suggest that it is vital to include plyometric depth jump training to a current program in order to improve vertical jump ability (Gehri, Ricard, Kleiner, & Kirkendall, 1998). Behm and Sale suggest that it may be the intention to move quickly, and not the actual speed moved that would elicit a velocity specific response (Behm & Sale, Velocity specificity of resistance training, 1993). In other words, it may not be the movement speed that is important, as long as an explosive movement is produced. However, McBride et al did not support this theory in their investigation (McBride, Triplett-McBride, Davie, & Newton, The Effect of Heavy-Vs. Light- Load Jump Squats on the development of Strength, Power, and Speed, 2002). McBride et al argued that in their investigation, Behm and Sale did not as the participants to accelerate the resistance as quickly as possible. There are no known studies which compared heavy and light load training in which both groups attempted to move the loads as quickly as possible without a deceleration phase, which is typical of traditional weight training (McBride, Triplett-McBride, Davie, & Newton, The Effect of Heavy-Vs. Light- Load Jump Squats on the development of Strength, Power, and Speed, 2002). Kraemer et al suggests formatting an exercise program around competition days, with the loads varying on the proximity to a competition (Kraemer & Newton, 1994); the training program is divided into three phases that have loading variations. The preparation phase is marked by weight training to increase muscle mass and strength (Kraemer & Newton, 1994). The pre-competition phase requires heavier and more specific weight training; often a base of more explosive weight training, emphasizing rate of force development, the stretch-shortening cycle, and high contraction velocities (Kraemer & Newton, 1994). The competition phase involves maintain of vertical jump performance and emphasizes removal of plyometrics, reduced heavy weight training, and not ceasing exercise until five to six days prior to competition(Kraemer & Newton, 1994).

An area of concern for athletic coaches is improvements in not only the weaker athletes, but also, stronger athletes. Cormie et al proved that an experimental training regime can improve athletic performance in both stronger and weaker individuals, and the practical differences between the two groups was distinct at 5 weeks and lessened within 10 weeks of the study (Cormie, McGuigan, & Newton, Influence of Strength on Magnitude and Mechanisms of Adaptation to Power Training, 2010). This suggests that both stronger and weaker individuals receive rapid improvements from ballistic power training (Cormie, McGuigan, & Newton, Adaptations in Athletic Performance after Ballistic Power versus Strength Training, 2010). While improving the athletic performance of weak athletes is imperative for trainers and coaches, it is equally important to continue to strengthen already strong athletes. However, in order to improve the athletic performance of well-trained athletes, it is necessary to develop a sophisticated resistance training program that has specificity and variability(Cormie, McGuigan, & Newton, Adaptations in Athletic Performance after Ballistic Power versus Strength Training, 2010).

For the lower body, vertical jump ability is often used to assess explosive strength (Kraemer & Newton, 1994)(Channell & Barfield, 2008). Vertical jump strength is dependent on strength, power, and the ability of the muscle to use SSC (Channell & Barfield, 2008), therefore it can be determined that a visible increase in vertical jump strength would lead to an increase in athletic performance. Several studies focus on building vertical jump ability in weak and strong groups to provide proof of an increase in athletic performance. Cormie et al assessed studied the influence of strength on mechanisms of adaption to power training, and found that athletic performance was improved through their experiment by testing the power output during CMJ (Cormie, McGuigan, & Newton, Adaptations in Athletic Performance after Ballistic Power versus Strength Training, 2010).

Power can be defined as work divided by time (Stone, O'Bryant, McCoy, Coglianese, Lehmkuhl, & Schilling, 2003). One of the major separating factors of athletes is their ability to generate great power (Stone et al 2003). An athlete is able to achieve peak power (PP) when force and velocity are at optimum values; this is the highest possible power generated in a performance. Maximum strength is the basic factorial unit of power output (Stone, O'Bryant, McCoy, Coglianese, Lehmkuhl, & Schilling, 2003); therefore it can be assumed that by achieving maximum strength, an athlete will achieve the highest possible power output. In a study about power relationships during jumps, Stone et al concluded that as one rep max (1RM) percentages increased in trained, and untrained individuals, the rate at which peak power occurs also increases (Stone, O'Bryant, McCoy, Coglianese, Lehmkuhl, & Schilling, 2003). This leads to the assumption that in order to improve jumping power output, improving maximum strength would be the primary concern (Stone, O'Bryant, McCoy, Coglianese, Lehmkuhl, & Schilling, 2003). When estimating explosive power in the lower limbs, CMJ and SJ are the most reliable and valid field tests

(Markovic, Dizdar, Jukic, & Cardinale, 2004); and CMJ has proven to produce power greater than SJ (Stone, O'Bryant, McCoy, Coglianese, Lehmkuhl, & Schilling, 2003).

It is not uncommon for athletes to be weight conscious, especially in sports that involve a lot of power. While a heavier athlete would require a higher power output to perform an explosive movement, such as a vertical jump, a lighter counterpart would require substantially less power (Kraemer & Newton, 1994). Many athletic trainers take intuitive leaps, and theorize that a lighter athlete would be able to jump higher; therefore, strength training should be diminished (Kraemer & Newton, 1994). Schmidtbleicher et al suggests that an increase in the cross sectional area of the muscle, by increasing muscle size, would lead to an increase in strength. This would lead to a preferred, and improved, power-to-weight ratio (Schmidtbleicher,D.,1992. Training for power events. In: P.V. Komi (ed.) Strengthand Power in Sport. Boston: Blackwell Scientific Pub., pp. 381-395). Body fat percentage, as well as body mass, is an area of concern in many explosive sports. Although athletic trainers, and athletes, may seek low body fat percentages in hopes of increasing jump height, Ashley et al found no significant correlation between jumping performance and body weight (Ashley & Weiss, 1994). However, Weiss et al also found a negative relationship between peak force and percent body fat, and as body fat percentage increased, the ability to generate a high force velocity decreased (Weiss, Relyea, Ashley, & Propst, 1997).

Explosive strength has been proven to be one and the same with maximal power (McBride, Triplett-McBride, Davie, & Newton, A Comparison of Strength and Power Characteristics Between Power Lifters, Olympic Lifters, and Sprinters, 1999). The development of muscular power is influenced from a multitude of factors, including maximal strength (Cormie, McGuigan, & Newton, Influence of Strength on Magnitude and Mechanisms of Adaptation to Power Training, 2010). Strength is defined as maximal force production (Newton R. W., 1996)and a positive relationship between maximal strength and maximal power production (Baker & Nance, 1999). The ability of an athlete to generate high power output is characterized by the muscle actions and high movement velocities generated by the muscle (Newton R. W., 1996). Because many sports involve high force generation movements over a short period of time (McBride 1999), the ability to achieve maximal force and power is beneficial. Wisloff et al determined that achieving maximal strength in half squats determines jump height in high level soccer players. A focus on maximal strength training, with an emphasis on mobilization of concentric movements, will improve jumping performance (Wisloff, Casagna, Helgerud, Jones, & Hoff, 2004). Since jumping performance is a derivative of maximal strength (Wisloff, Casagna, Helgerud, Jones, & Hoff, 2004), it can be determined that improving maximal strength will improve vertical jump ability (Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003). Physiologically, initial improvements in strength after strength training are greater and largely driven by neural adaptations (Cormie, McGuigan, & Newton, Influence of Strength on Magnitude and Mechanisms of Adaptation to Power Training, 2010). These neuromuscular characteristics form the foundation for superior maximal power production (Cormie, McGuigan, & Newton, Influence of Strength on Magnitude and Mechanisms of Adaptation to Power Training, 2010). Individuals with greater levels of strength have larger whole-muscle cross sectional area, and a greater number of Type I and Type II muscle fibers (Hakkinen, Komi, & Tesch, Effect of combined concentric and eccentric strength training and detraining on force-time, muscle fibre and metabolic characteristics of leg extensor muscles, 1981). Through comparisons of cross sectional areas, stronger individuals have superior power production compared to their weaker counterparts (Bourque, 2003).

Rate of force development (RFD) is the ability to rapidly develop muscular force, and is determined by the slope torque-time curve (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). Rate of force development is defined as the rate of rise of contractile force at the beginning of a muscle action (Ebben, Flanagan, & Jensen, 2007), and is a major contributor to vertical jump performance (Kraemer & Newton, 1994). Another importance of RFD is the ability to use it to determine the force generated at the beginning of a muscle contraction (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). The maximal rate of force development (mRFD) is determined from the maximal portion of a time curve taken during maximal strength tests (Kraemer & Newton, 1994). Ebben et al suggests that RFD is manifested within the short and long term components of the stretch-shortening cycle (Ebben, Flanagan, & Jensen, 2007). The short component occurs during the initial 100-250 ms of muscle activation when small angular displacements occur in the lower body during sprinting or quick jumping (Ebben, Flanagan, & Jensen, 2007) (Schmidtbleicher,D.,1992. Training for power events. In: P.V. Komi (ed.) Strengthand Power in Sport. Boston: Blackwell Scientific Pub., pp. 381-395). The long component occurs in muscle activation that lasts longer than 250 ms when large angular displacements of the lower body occur, typically during maximal vertical jumps (Haff GG, 1997). Maximal rate of force development is primarily expressed in movements that occur less than 250 ms; maximal strength often occurs in movements that last longer than 250 ms (Ebben, Flanagan, & Jensen, 2007). Haff et al. demonstrated that countermovement jump generates greater time to peak RFD and time to peak force than isometric and loaded mid-thigh pulls (Ebben, Flanagan, & Jensen, 2007). This suggests that there are other factors to the time course of RFD than maximal strength and external load (Ebben, Flanagan, & Jensen, 2007). Ebben et al. found through their investigation an absence of correlation between RFD and countermovement jump height (Ebben, Flanagan, & Jensen, 2007). This leads to the question if RFD is useful in measuring an athlete's maximal vertical jump abilities (Ebben, Flanagan, & Jensen, 2007). Ebben et al. suggest this is due to variability in which the countermovement jump is a high force or a high velocity activity (Ebben, Flanagan, & Jensen, 2007). Through further investigations, it has been determined that body mass and training status does not affect the relationship between RFD and jump height (Ebben, Flanagan, & Jensen, 2007).

Strength and power are often used to assess an athlete's performance (Brown & Weir, 2001)and athletic coaches often focus on strength building exercises because of this. The ability to generate power is a major separating factor between athletes (Stone, O'Bryant, McCoy, Coglianese, Lehmkuhl, & Schilling, 2003). The ability of an athlete to achieve maximal force and power is beneficial because many sports involve high force movements within a short period of time (McBride, Triplett-McBride, Davie, & Newton, A Comparison of Strength and Power Characteristics Between Power Lifters, Olympic Lifters, and Sprinters, 1999). Focusing on maximal strength training can improve jumping performance (Wisloff, Casagna, Helgerud, Jones, & Hoff, 2004). Improving maximal strength can improve vertical jump ability (Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003)since jumping performance is a derivative of maximal strength (Wisloff, Casagna, Helgerud, Jones, & Hoff, 2004). Often in explosive sports, body fat percentage and body mass are an area of concern among athletes. It is a common misconception that extreme weight loss will elicit improvements in athletic performance (Wilmore, Bownell, Rodin, & Wilmore, 1992). Increases in fat mass can have a negative implication on sports performance (Rickenlund, Carlstrom, Ekblom, Brismar, Von Schoultz, & Linden Hirschberg, 2004) however; following body composition measures too closely can have negative consequences on an athlete such as the female athlete triad (Yeager, Agostini, Nattiv, & Drinkwater, 1993). Studies have also elicited results that prove either no correlation, or negative correlation between jumping performance or peak force, and body weight or percent body fat (Ashley & Weiss, 1994) (Weiss, Relyea, Ashley, & Propst, 1997).

Methods

Subjects

Data from eleven female NCAA DI volleyball players collected from 2007-2010 as part of an ongoing athlete monitoring program was analyzed. Athlete (n = 11) characteristics are listed in **Table 1.** These athletes had limited participation in strength training programs prior to competing at the intercollegiate level. Data was separated into weakest and strongest based on allometrically scaled isometric peak force, using the same eleven participants. In all cases the weakest data corresponded to testing during the athletes first year at ETSU. The strongest data corresponds to testing during the most recent year (2010) of data collection for athletes. Athletes in the strongest group had an average of 1.8 years of training when their data was collected. In accordance with the guidelines of East Tennessee State University's Institutional Review Board, participants read and signed written informed consent documents pertaining to the long-term athlete monitoring program and all testing procedures.

Experimental Design

Data was collected as a part of a voluntary long-term athlete-monitoring program of East Tennessee State University, analyzed and then evaluated for relationships. Athletes were familiarized with all testing procedures prior to taking part in the monitoring program. Testing included SJ, CMJ, and isometric mid-thigh pulls; bar heights were measured prior to testing day. Maximal effort testing was conducted in one session. Each session began with biometric data collected upon arrival, followed by the vertical jumps, a three-minute rest period, and isometric mid-thigh clean pulls.

Subject Characteristics

Biometric data was obtained prior to vertical jump and isometric mid-thigh clean pulls. Biometric data included: height (cm), body mass (Kg) and body composition. Height was measured to the nearest 0.1 cm using a stadiometer. Body mass was measured using an electronic scale. Body composition was measured using BodPod air displacement plethsmography instrumentation (Life Measurement Incorporated, Concord, CA), with standard procedures using an estimated thoracic gas volume.

<u>Testing Methods</u>

Vertical Jump Testing Procedures

Prior to vertical jump and strength testing procedures, a standardized warm-up was followed for all participants. The warm-up consisted of twenty five jumping jacks, a series of clean pulls (one set of five clean pulls at mid-thigh with an empty barbell and three sets of clean pulls at mid-thigh with 40 Kg). Then a series of jumps, either static jump (SJ) or countermovement jump (CMJ) followed. Each jump was performed with 0 Kg using a PVC pipe or 20 Kg barbell placed upon the athletes' shoulders between the seventh cervical vertebrae and the third thoracic vertebrae. Before the maximal effort tests began, athletes performed two unloaded practice jumps, one at 50 % effort, and one at 75% perceived effort. CMJ and SJ jumps were performed, with approximately one minute rest in between.

Vertical jump testing began with SJ conditions. Prior experimentation within the laboratory has proven no significance difference between the orders of a SJ or CMJ (Kinser et al 2008). Athletes performed all jumps on a force plate (Rice Lake, WI) that had a sampling rate of 1000 Hz. Once stepping on the force plate, the athlete was instructed to obtain the "ready position" which consisted of holding the PVC pipe (0 Kg) or the barbell (20 Kg) and assuming the squat position with a 90° knee angle. The knee angle was measured with a hand held goniometer. Once the athlete is in the position, a countdown of "3, 2, 1, Jump" was given to initiate jump time. To eliminate use of the stretch-shortening cycle, a three second hold at the bottom position was used (Haff 1997). Two sessions of each jump (SJ with 0 Kg, SJ with 20 Kg) with a one minute rest between were completed. After completion of the SJ sessions, athletes were given a three minute rest before beginning CMJ procedure.

CMJ were performed using procedures from prior research (Haff 1997). Athletes were allowed two practice weighted jumps. CMJ were completed without a pause after self-selected countermovement depth. Athletes completed two trials for both conditions (CMJ with 0 Kg and CMJ with 20 Kg) with a one minute rest between each repetition. If the athlete, or investigator, perceived any jump (SJ or CMJ) as not maximal effort, the jump was repeated.

As described in previous studies, vertical jump height (JH) was calculated from flight time (FT) (Bosco et al 1983). SJ and CMJ force-time curve characteristics were recorded and analyzed using LabView 8.0 software (National Instruments, Upper Saddle River, NJ). Jump height difference was calculated as a percent loss from the average jump height achieved under 0 kg loading conditions; Percent loss = (Jump Height at 0 kg – Jump Height under 20 kg)/ Jump Height at 0 kg.

Isometric Strength Testing Protocol

Athletes were given a three minute rest period after the vertical jump tests, before beginning the isometric mid-thigh clean pulls. All pulls were performed in a custom designed rack over a force plate (Rice Lake, WI) with a sampling rate of 1000 Hz. Each athlete was given two trials pulls, one at 50 % effort, and another at 75 % effort, with forty-five second rest in between. Athletes were then instructed to pull up as fast and hard as possible, which has been proven to produce optimal testing results (Bemben et al 1990). Athletes were instructed when to pull through a countdown "3, 2, 1". In between the two maximal effort pulls, the athlete is given a one minute rest. A third attempt was performed if the athlete or investigator felt the pull was below maximal effort, or if there was greater than a 250 N difference in the initial two pulls. If a third pull was conducted, the two best isometric mid-thigh clean pulls were recorded for analysis.

Isometric peak force (IPF), isometric rate of force development (IRFD), and the forces at 50 ms (F50), 90 ms (F90) and 250 ms (F250) were calculated from the force-time curve, and were measured for each isometric mid-thigh pull. LabView 8.0 software (National Instruments, Upper Saddle River, NJ) was used during testing, recording, and force-time curve analysis. Maximal strength was measured in both absolute and normalized values.

Statistics

Allometric scaling of the different force values (IPFa, F@50a, F@90a, F@250a) was used to normalize differences in the body mass of the athletes (absolute force/ (body mass ($kg^{0.67}$)). Pearson correlations were done comparing both Highest and Lowest SJ 0kg with all other variables and Highest and Lowest SJ 20kg with all other variables. Strength of relationships in correlations was assessed using the following criteria: trivial (r < 0.001), small (r = 0.1 to 0.2), moderate (r = 0.3 to 0.4), and strong (r = 0.5 to 0.6), very strong (r = 0.7 to 0.8), nearly perfect (r = 0.9), and perfect (r = 1.0) (Hopkins, 1997). Two-tailed independent T-tests were used to assess differences between variables.

Results

Biometric Comparisons

There is no significant difference in height, weight, or percent body fat data between the strong and weak athletes.

Table 1: Subject Characteristics

	Weakest Test Results	Strongest Test Results
	Mean ± SD	Mean ± SD
Height (cm)	175.55 ± 4.12	175.56 ± 4.12
Weight (kg)	69.45 ± 9.55	69.11 ± 9.53
% BF	18.73 ± 5.96	18.68± 5.28

Jump Heights and Strength Comparisons

Differences in strength characteristics between the strongest and weakest athletes are listed in Table 2. There is a significant difference ($p<0.05$) in CMJ, IPF, IPFa, and IPF250a between strong and weak athletes, and no significant difference ($p> 0.05$) in F250 ms and RFD between strong and weak athletes.

Table 2: Jump Height and Strength Characteristics

	Weakest Test Results	Strongest Test Results
	Mean ± SD	Mean ± SD
CMJ Height (cm)	26.40 ± 3.13	32.60 ± 5.00*
IPF (N)	2396.30 ± 373.36	3067.06 ± 418.37*
IPFa (N/kg)	141.30 ± 17.05	180.74 ± 17.46*
IPF(N) @ 250 ms	1653.53 ± 357.06	1975.57 ± 403.45*
IPFa (N/kg)@ 250 ms	97.41 ± 18.11	116.20 ± 20.73*
RFD(N/s) (0-200 ms)	3505.51 ± 1141.49	4450.72 ± 1479.56*

* There is a significant difference compared to weak athletes ($p \geq 0.05$)

Countermovement Jump Comparisons

All Pearson correlations are presented in Table 3. In weaker test results, there were small inverse correlations between CMJ and PF (r= -0.34 CMJ Wt 0, r= -0.37 CMJ Wt 11, r=-0.12 CMJ Wt 20) and PFa (r= -0.19 CMJ Wt 0, r= -0.34 CMJ Wt 11, r= -0.12 CMJ Wt 20), strong inverse correlations between CMJ and percent body fat (r=-0.67 CMJ Wt 0, r= -0.65 CMJ Wt 11). However, during the weighted jumps, a moderate inverse relationship is seen between percent body fat and CMJ Wt 20 (r=-0.35). In Stronger athletes there are small correlations between CMJ and PF (r=0.23 CMJ Wt 0, r= 0.13 CMJ Wt 11, r=0.28 CMJ Wt 20), PFa (r= 0.26 CMJ Wt 0, r=0.15 CMJ Wt 11, r= 0.19 CMJ Wt 20), and moderate inverse correlations between CMJ and percent body fat (r=-0.40 CMJ Wt 0, r=-0.40 CMJ Wt 11, r=-0.42 CMJ Wt 20). While there is no strong correlation in the variables measured, there is a trend towards significant correlation between the strong and weak test results. In the stronger test results there is a trend towards a more significant correlation in strength variables.

Table 3: Correlations to Countermovement Jump

Weakest Test Results	% Fat	PF (N)	PFa (N/kg)	F250 (N)	F250a (N/kg)	RFD (N/s)
CMJ Wt 0	-0.67	-0.34	-0.19	-0.31	-0.19	-0.03
CMJ Wt 11	-0.65	-0.37	-0.34	-0.11	-0.03	0.18
CMJ Wt 20	-0.35	-0.12	-0.12	0.13	0.19	0.44

Strongest Test Results	% Fat	PF (N)	PFa (N/kg)	F250 (N)	F250a (N/kg)	RFD (N/s)
CMJ Wt 0	-0.40	0.23	0.26	0.25	0.28	0.15
CMJ Wt 11	-0.40	0.13	0.15	0.24	0.26	0.17
CMJ Wt 20	-0.42	0.28	0.19	0.26	0.21	0.15

Strength Characteristics Comparisons

All Pearson correlations are presented in Table 4. In weaker test results, the inverse relationship between BF and CMJ becomes stronger. As test results become stronger, there is a stronger positive relationship between LBM and PF, PFa, F250, F250a and RFD. As test results become weaker, there is a stronger relationship between BF and PF, PFa, F250, F250a and RFD. As 20 kg weight is added to CMJ, there is a trend towards stronger inverse relationships between CMJ and BF.

Table 4: Correlations to Strength Characteristics

Weakest Test Results	CMJ Wt 0	CMJ Wt 11	CMJ Wt 20	PF (N)	PFa (N/kg)	F250 (N)	F250a (N/kg)	RFD (N/s)
LBM	0.08	0.18	0.15	0.38	-0.05	0.28	-0.003	-0.01
% Fat	-0.67	-0.65	-0.35	0.70	0.45	0.51	0.31	0.26

Strongest Test Results	CMJ Wt 0	CMJ Wt 11	CMJ Wt 20	PF (N)	PFa (N/kg)	F250 (N)	F250a (N/kg)	RFD (N/s)
LBM	0.25	0.17	0.40	0.82	0.22	0.50	0.10	0.13
% Fat	-0.40	-0.40	-0.42	0.12	0.26	0.33	0.11	0.19

Discussion

There are three main findings with this investigation. The first is that over the training period the athletes got stronger as evident by significant increases in strength measures and significantly increased vertical jump height. This increase in strength and jump height was accomplished without a significant change in their body weight or body composition. Another finding is in the athletes' stronger test results, there is a trend towards a more positive correlation with CMJ height, PF, PFa, F250, and F250a. The third significant finding is the relationship between body fat percentage (BF) and the strength characteristics. Data from athletes in the weakest group was collected during initial testing. These athletes were new to the conditioning program and were considered untrained. At this time, there tended to be a strong relationship between percent BF and CMJ height. As athletes increase strength levels the relationship between percent BF and VJ become less strong.

Stronger test results have a strong positive correlation between CMJ height and strength characteristics. Therefore, increasing an athlete's strength in this study resulted in an increase in jump height. These results are in agreement with other research. In a study done on twenty four men examining power training found that ballistic training significantly improved power and jump height (Cormie, McGuigan, & Newton, 2010). Another study examining twelve male football and track NCAA athletes found that multi-joint dynamic strength test are closely related to jump performance (Nuzzo, McBride, Cormie, & McCaulley, 2008). This suggests that increases in maximal strength could elicit improvements in jump performance.

As the correlation between CMJ and strength characteristics increase, the correlation between CMJ and %BF decreases. Inversely with the athletes' weaker test results a higher percent BF is related to a decrease in CMJ height. When weight is added to a VJ, a steep drop in jump height is evidence of diminished strength characteristics(Kraska, 2008). However the strength of the correlation decreases as

20 kg weight is added to CMJ. As an athlete becomes stronger, there is a stronger positive relationship between BM, PF and PFa; in lower levels of strength there is a stronger relationship between %BF and PF. In a study measuring the association between CMJ and various musculoskeletal variables done on fifty healthy university women, Ashley et al found no significant correlation between jump performance and BF (Ashley & Weiss, 1994). This study used females aged 18 to 23 years old, with varying activity backgrounds. While we found a strong relationship in our athletic population, using a different population could cause explain the differences in findings.

These results show that strength characteristics and body composition should not be overlooked in athletic training. A study conducted by Weiss et al examined restricted standing vertical jumps (RVJ) in healthy, college aged males and females. This study found that excessive body fat decreased the distance achieved (Weiss, Relyea, Ashley, & Propst, 1997). Also, a study done on intercollegiate male basketball players over the course of four years found that while body fat percentages remained relatively stable, increases in body mass due to increases in muscle mass caused strength gains that directly increased power and jump ability performance (Hilyer, Forster, & Hunter, 1993). This study suggests that increases in muscle mass will elicit increases in performance, regardless of body fat. Therefore, it may be beneficial to focus on strength characteristics rather than body fat in promoting power and jump ability.

This study had some minor limitations. To begin with, data was collected with athletes. Athletes are a unique group of the population; they tend to be in better physiological shape and stronger. This provided the study with no means of a control group for comparisons. Due to the competitive nature of athletics it would be impractical to make untrained subgroups because it would hinder athletic performance. Another limitation is the inability to control all physical activities prior to testing. This could lead to the athletes being exhausted, and therefore not being able to complete testing protocols to the best of their abilities. However the testing sessions were incorporated into this overall training program and volume was reduced prior to testing to minimize fatigue. Furthermore athletes and coaches were instructed to keep activities low the day prior and the day of testing.

Practical Applications

This data suggests that conditioning programs for female volleyball players should be focused around strength gains instead of fat or weight loss. Having the correct goal behind a program will help improve athletic performance. This data could also be shown to female volleyball players to encourage them to continue their training, and proper nutrition without the concern of their body composition.

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