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Relationship Between Lower Body Strength, Countermovement Jump Height, and Optimal Drop Jump Drop Height

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by

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ABSTRACT

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The purpose of this study was to understand the relationship between back squat one-repetition maximum relative to body mass (1RMrel), countermovement jump height (CMJH), and optimal drop height in drop jump (DHopt). Fifteen male participants completed a one repetition maximum (1RM) back squat, maximum countermovement jump (CMJ), and drop jumps (DJ) from incrementally increasing drop heights to determine which drop height elicited the greatest jump height. Pearson correlation coefficients revealed that DHopt had small (r=0.214) and moderate (r=0.464) relationships with 1RMrel and CMJH, respectively. A second analysis (n=13) was conducted after two participants (i.e. powerlifters) were identified as possibly being representative of a different population. The second analysis found that DHopt had strong relationships with 1RMrel (r=0.645) and CMJH (r=0.690). Results from this study seem to suggest that individuals with greater 1RMrel and CMJH tend to have a higher DHopt. However, this relationship may not be observed among all populations.

DEDICATION

This thesis is dedicated first to my best friend and father, Ricky. He is my biggest fan and greatest critic. Second, I dedicate this thesis to my grandparents, J.D. and Jean. Without them, I would not be here today. Last, I dedicate this thesis to Justin Roberts (April 18, 1992 - June 8, 2016). Justin will be missed by everyone.

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CHAPTER 1

INTRODUCTION

Strength and conditioning practitioners commonly use the vertical jump as a test to measure explosive strength. The vertical jump has been used as a form of monitoring to periodically test progress between phases of training or preparedness before competition (Chiang, McInnis, & Sato, 2012). Testing vertical jump is simple and allows practitioners with only rudimentary equipment to assess an athlete's force producing capabilities. Beyond testing and monitoring vertical jumps can be used in training, specifically for developing force rapidly. The strength and conditioning coach or sport coach will often incorporate variations of the vertical jump into training, including the squat jump, countermovement jump, or drop jump depending on the aim of training. Unfortunately, observations in practice suggest these variations are often misunderstood and misused by sport coaches.

The drop jump, or depth jump as it was originally called, is a variation of vertical jumping that has been used by strength and conditioning practitioners since Dr. Yuri Verkhoshansky first employed them in the 1960's with Track and Field jumpers (Verkhoshansky & Verkhoshansky, 2011). When performing a drop jump the athlete steps off a platform at a given height; upon landing they quickly rebound, jumping as high as possible with minimal ground contact time. Dr. Verkhoshansky developed drop jumps to imitate the high ground forces observed during triple jumping. These forces have been reported to exceed 15 times body mass (Perttunen, Kyrolainen, Komi, & Heinonen, 2000). Simply squatting with a supramaximal load or performing standard loaded jumps was not sufficient in recreating the forces seen during the triple jump. Dropping from a height, however, imposes a great stimulus on the athlete without loading the spine with a heavy barbell. The drop jump is possibly the most intense form of vertical jumping as it exhibits higher ground reaction force and rate of force development than squat jumps (Ebben, Fauth, Kaufmann, & Petushek, 2010). Furthermore, the drop jump demonstrates higher jump height and peak vertical ground reaction force than countermovement jumps or squat jumps (Earp et al., 2011) when drop height is set at 30 cm. These findings suggest that the drop jump is a powerful stimulus capable of stressing the athlete's neuro-muscular systems in a way that traditional vertical jumps cannot. The drop jump is not only used in training for long-term performance improvements but also to potentiate performance acutely. A study conducted by Byrne, Kenny, and Rourke (2014) found a dynamic warm-up including drop jumps 1 minute prior to a 20 m sprint improved sprint time in 93% of subjects. Terzis, Spengos, Karampatsos, Manta, and Georgiadis (2009) found similar improvements when subjects performed multiple drop jumps immediately before an underhand shot throw. These acute performance improvements are likely due to an increased tone of the neural and muscular systems and recruitment of higher order motor units (Güllich & Schmidtbleicher, 1996).

It should be mentioned here that disagreements exist among researchers and practitioners when defining what constitutes a drop jump. The terms drop jump and depth jump are often used interchangeably. Dr. Yuri Verkhoshansky, founder of the "shock method", defined depth jump as a drop from height, followed by an immediate vertical rebound. Alternatively, Verkhoshansky defined drop jump as a drop from a height without a vertical rebound (Verkoshansky & Verkhoshansky, 2011). These exercises were meant to be applied differently in training with each exercise focusing on different components of athlete development. However, when examining research today, drop jumps are often used to describe a form of jumping that includes a vertical rebound upon landing from a drop (Baca, 1999; Chen, Wang, Peng, Yu, & Wang, 2013; Earp et al., 2011; Feldmann, Weiss, Schilling, & Whitehead, 2012; Kristianslund &

Krosshaug, 2013). In this thesis a drop jump is used to describe a drop from height followed by an immediate vertical rebound since this definition has gained popularity among researchers.

An important mechanism contributing to the higher force outputs of dynamic vertical jumps, such as the drop jump, compared to static vertical jumps is the stretch-shortening cycle. The stretch-shortening cycle describes the rapid shortening of a muscle following a rapid stretch of a muscle-tendon unit, allowing the conversion of elastic potential energy to kinetic energy (Cavagna, Citterio, & Jacini, 1975). This function of the muscle produces a more forceful and powerful contraction that would otherwise not be possible with a single isolated muscle action (Edman, Elzinga, & Noble, 1978). Deformation of the muscle tendon unit and muscle spindles during the eccentric phase also activates the stretch reflex mechanism, eliciting a more powerful shortening of the muscle fibers (Bosco, Viitasalo, Komi, & Luhtanen,1982). The drop jump offers a different stimulus than other forms of vertical jumping because of higher eccentric forces imposed when dropping from a height (Aboodarda et al., 2014). Although previous research has shown the drop jump to be superior to other forms of jumping when certain performance variables are measured (Ebben et al., 2010), the amount of research comparing all forms of vertical jumping simultaneously is limited and most researchers exclude the drop jump from the jumping protocol (Carlock et al., 2004; Hornsby, 2013; Sams, 2014).

Existing literature is equivocal regarding application and assessment of the drop jump. The drop height from which the drop jump is performed is a point of contention within sport science with various methods being used to determine "optimal" drop height. Research conducted by Byrne et al. (2014) and Ebben et al. (2010) used a drop height that was equivalent to maximal CMJ height. Some researchers consider optimal drop height to be the height at which the reactive strength index is highest. The reactive strength index is calculated by dividing the jump height by ground contact time. Other researchers, such as Baca (1999) and Ball and Zanetti (2012), chose a single drop height for all subjects regardless of possible differences in strength and jumping ability. Determining optimal drop height is highly dependent on the drop jump variables being measured. A higher dropping height will lead to longer ground contact time and perhaps a higher jump to a point. However, jump height may be sacrificed if a shorter ground contact time is prioritized (Walsh, Arampatzis, Schade, & Bruggemann, 2004). Barr and Nolte (2011) suggest that maximal jump height achieved from a drop jump is the most important measure. To the author's knowledge all prior studies on the topic lack precision in determining drop height on an individualized basis. Most studies have subjects jump from heights that increase by intervals of 10 cm for each trial (Barr & Nolte, 2011; Bassa, Patikas, Panagiotidou, Pyliandis, & Kotzamanidis, 2012; Byrne et al., 2014). Other researchers have increased height between trials by up to 20 cm (Walsh et al., 2004). Inconsistencies within research have led to confusion in its practical application.

Drop jumping ability depends greatly on the strength of an athlete and their performance in other jumping tasks (Carlock et al., 2004, Peterson, Alvar, & Rhea, 2006). Barr and Nolte (2014) found a large correlation between drop jump height and predicted maximal back squat strength in female rugby players and concluded that stronger athletes were able to attenuate a decline in performance at higher dropping heights. Prepubescent children with limited training experience also out perform their untrained counterparts in drop jumps of various heights (Bassa et al., 2012). From these results one could assume that stronger individuals are able to overcome higher eccentric forces at greater dropping heights while weaker individuals suffer from a longer transition phase when landing, thus diminishing benefits from the stretch shortening cycle. It is often recommended that weaker individuals develop sufficient strength before attempting DJs to avoid injury due to the high impact forces incurred from these jumps (Baechle & Earle, 2008; Siff, 2003). Other strength related variables such as fascicle length and pennation angles of lower body muscles have been found to affect force production and rate of force development during jumping as well (Earp et al., 2011).

Given the variables previously mentioned it still remains common practice in strength and conditioning to prescribe a universal drop height for all athletes performing drop jumps. It is not rare to see an entire team of athletes drop jumping from a single box during a training session. Practices like these defy basic principles of training such as individualization, variation, and specificity (Stone, Stone, & Sands, 2007). More research is needed to discover a method by which determination of optimal drop height can be achieved based on an individual's lower body strength and jumping ability in other vertical jumping tasks. Without ascertaining the optimal drop height for each athlete, it is impossible to accurately prescribe drop heights for various intensities throughout a training program.

Definitions

1. One-Repetition Maximum (1RM) - The maximum load that an individual can successfully lift for one repetition.
2. Lower Body Strength - The strength of the lower body and torso musculature. Determined by an individual's 1RM back squat.
3. Countermovement Jump (CMJ) - A jump that requires an individual to start from an upright standing position. The individual initiates the jump with preliminary eccentric flexion of the hips, knees and ankles, followed immediately by forceful concentric extension of the hips, knees, and ankles.

4. Drop Jump (DJ) - An elevated jump that requires an individual to start from an upright standing position. The individual will drop from a given height and immediately rebound, jumping as high as possible (Verkhoshansky, 2011).
5. Drop Height - The height from which an individual descends during a drop jump.
6. Drop Jump Height - The height that an individual is able to jump after landing from a drop.
7. Optimal Drop Height - The drop height that elicits the highest drop jump height.

CHAPTER 2

REVIEW OF LITERATURE

Strength and conditioning practitioners often employ various forms of jumping throughout the annual training plan to test, monitor, or augment performance. Organizations such as the National Strength and Conditioning Association recommend the use of lower intensity jumps (e.g. hops and bounds) for beginners and weaker athletes (Baechle & Earle, 2008). Stronger and more experiences athletes can safely perform higher intensity jumps (e.g. drop jumps), providing a greater stimulus and adaptation to training as a result. Most practitioners, however, do not understand the proper function of these various jump types or how the jumps should be implemented into the training plan.

While the vertical countermovement jump is ubiquitous in research and practice, the drop jump is comparatively ambiguous. Research has yielded mixed results in regard to drop jumping technique (Bobbert, Huijing, & van Ingen Schenau, 1987), determining optimal drop jump drop height (Matic et al., 2015), and methods for analyzing drop jumps (Baca, 1999). The equivocal results found in current literature have made it very difficult for practitioners to accurately prescribe drop heights for their athletes based on individual performance characteristics.

This comprehensive review of literature examines the most popular methods for determining optimal drop height. The review will also investigate the relationships of strength and conventional forms of jumping with drop jumping ability in order to elucidate the dependence of optimal drop height on other performance characteristics of an athlete.

Influence of Jumping Ability in Sport

The ability to jump is important in many sports that inherently require jumping for success such as long jump, high jump, and triple jump in track and field. In these sports, jumping ability ultimately determines the outcome of competition. However, the ability to jump high is also important in the sports of weightlifting, football, volleyball, or any sport with a high power component (Carlock et al., 2004; Robbins & Young, 2012; Sheppard, Nolan, & Newton, 2012). Interestingly, Hudgins, Scharfenberg, Triplett, and McBride (2013) found significant negative correlations with two-leg standing long jump distance and performance times in 3,000 m and 5,000 m distance runners, which suggests that power output is important in endurance-based sports as well.

The jumping ability of an athlete should reflect the power output and force-time parameters exhibited in their respective sport. For example, volleyball players were found to have greater jump heights from 60 cm drop jumps compared to soccer, handball, basketball, track and field, and rowing athletes, but the track and field athletes had the highest peak force and power outputs due to shorter ground contact times (Kollias, Panoutsakopoulos, & Papaiakovou, 2004). Power describes the rate of which work (work/time) is accomplished (Stone et al., 2007). Different measures of power (e.g. average and peak) can be analyzed to assess the rate of work performed by an athlete. Peak power is the highest instantaneous value of power achieved during a single movement (Cormie, McGuigan, & Newton, 2011). Peak power production is arguably the most important measure in strength-power sports (Stone et al., 2007) as peak power values have been associated with sporting success in weightlifting, powerlifting, and sprinting (Garhammer 1993; Mcbride et al., 1999).

Power measurements typically require expensive software and equipment. Some researchers have developed power prediction equations that require only static jump or countermovement jump height and the mass of the athlete (Sands, Stone, McNeal, Jemni, & Haff, 2006). Calculating power with prediction equations should be used with caution, particularly if the equations do not account for changes in system mass or acceleration when loading is manipulated (Crewther, Cronin, & Keogh, 2006). Training and monitoring vertical jumps has become ubiquitous in practice for its similarity to sporting movements and its ease of administration on the field or in the lab (Klavora, 2000). Testing vertical jumps is a great way to determine power production and sporting success (Carlock et al., 2004; Hornsby, 2013; Israetel, 2013).

Jumping ability is associated with improved sport performance for many reasons. Athletes with greater countermovement jump performances have demonstrated better performances in agility tasks requiring quick changes of direction (Barnes et al., 2007). A study by Lockie et al. (2014) found horizontal and lateral jumps to have moderate negative correlations with multidirectional speed. In sprinting, drop jump performance was found to reflect maximal velocity better than any other type of jumping (Kale, A_çi, Bayrak, & Açikada, 2009). Bissas & Havenetidis (2008) also found maximal running velocity to have a strong correlation ($r=0.73$, $p<0.05$) with drop jumps from a drop height of 30 cm. When comparing horizontal and vertical countermovement jump performances in professional American football players, horizontal countermovement jump performance was a greater predictor of acceleration in start sprints between 9.1 and 36.6 meters while vertical countermovement jump performance was a greater predictor of maximum speed with the exception of quarterbacks (Robbins & Young, 2012). When comparing jumping performances among athletes it becomes apparent that jumping ability is associated with acceleration, speed, agility, power, coordination, and sport performance (Brughelli, Cronin, Levin, & Chaouachi, 2008; Carlock et al., 2004; Hornsby, 2013; Robbins & Young, 2012; Ziv & Lidor, 2010).

Strength: Predictor of Jumping Ability

Strength can be defined as the ability of the neuromuscular system to produce force against an external resistance (Stone et al., 2007). Whether the external resistance is gravity, air, water, a barbell, or an opponent, sufficient force must be developed to overcome these impediments. Previous studies have shown that a significant relationship exists between muscular strength and speed of movement (Baker & Nance, 1999; Bret, Rahmani, Dufour, Messonnier, & Lacour, 2002). Whether one is a sprinter or distance runner, a boxer throwing a punch or a thrower accelerating their projectile, sporting success depends upon the speed of execution (Siff, 2003) and therefore strength (Baker & Nance, 1999; Young, McLean, & Ardagna, 1995). Extant literature on long-term effects of strength training suggests that improvements in strength are associated with improvements in jumping ability and sport performance (Hornsby, 2013; Sheppard et al., 2012; Terzis, Georgiadis, Vassiliadou, & Manta, 2003; Thomas, Zebas, Bahrke, Araujo, & Etheridge, 1983; Wilson et al., 2012).

These improvements in performance are attributable to alterations in underlying anatomical and physiological characteristics of the lower body such as pennation angle, fascicle length, muscle fiber type, Achilles tendon length, and stiffness of the muscle-tendon units because of strength training and changes in power expression (Cormie et al., 2011). These characteristics have a strong influence on the jumping and force producing abilities of an athlete (Bojsen-Moller, Magnusson, Kjaer, & Aagard, 2005; Earp et al., 2011; Hunter et al., 2015; Ikegawa et al., 2008). Other researchers have also reported strong relationships between strength, jumping ability, and performance in sports such as weightlifting, volleyball, and track and field short-distance sprints (Carlock et al., 2004; Israetel, 2013; McBride et al., 1999; Sheppard et al., 2012). Research on aerobically trained athletes has shown implications for strength training as a means for improving 5 km running time, running economy, sprinting and jumping performance (Paavolainen, Hakkinen, Hamalainen, Nummels, & Rusko, 2003).

Research by Stone et al. (2003) found one-repetition maximum (1RM) back squat to have strong correlations (r=0.77-0.94) with countermovement and static jump power up to 90% of 1RM back squat. Some studies have found that as external resistance decreases maximal strength's contribution to power production decreases as well (Schmidtbleicher, 1992). Weaker individuals are not able to express power as effectively as stronger individuals relative to their 1RM in loaded jumping tasks (Stone et al., 2003). The inability of weaker or untrained persons to jump as high as str persons can be explained by disparities in the physical qualities mentioned previously as well as differences in mechanical efficiency.

Mechanical efficiency describes the ratio between work performed and energy expended (Kyröläinen et al., 2004). This type of movement efficiency is also referred to as economy in running activities. Verkhoshansky (1996) states "the adequate retrieval of elastic energy stored in the muscle complex, together with the stretch-shortening potentiation of force output, are valuable prerequisites for efficient high velocity cyclic and acyclic movement". Stronger, well-trained athletes are capable of optimizing the stored elastic energy developed during the eccentric phase more efficiently than weaker athletes, enabling stronger athletes to produce more force while expending less energy (McBride & Snyder, 2012). Research by Secomb et al. (2015) found stronger adolescent athletes to have greater hypertrophy of the vastus lateralis and lateral gastrocnemius than weaker athletes. This hypertrophy was presumably related to greater eccentric leg stiffness and less compliance of the muscle-tendon unit during jumps (Secomb et al., 2015). Overall, stronger individuals possess thicker contractile and non-contractile tissues of the muscle-tendon unit than weaker individuals (Csapo, Alegre, & Baron, 2011), facilitating more economical and powerful contractions (Bojsen-Moller, 2005).

Maximal strength is defined as the greatest magnitude of the voluntary force production an athlete can display when there is no time limit to complete the task (Verkhoshansky & Verkhoshansky, 2011), and it plays an increasingly dominant role in sport performance as external resistance encountered becomes greater (Siff, 2003). In *Supertraining* (2008), Mel Siff outlines many different qualities of strength and maintains that explosive strength is the ability most characteristic of sporting activities. Explosive strength is described as the ability to rapidly develop force and is related to contractile rate of force development (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulson, 2002). Clearly, parameters exists which limit the amount of time available for force production if one examines movements such as the snatch, clean and jerk, shotput throw, or high jump. The time allowed to exert force in explosive sporting movements is between 50 and 250 ms (Andersen & Aagaard, 2006). However, maximal muscular force requires more than 300 ms to develop (Sukop & Nelson, 1974; Thorstensson, Karlsson, Viitasalo, Luhtanen, & Komi, 1976), confirming that the ability of an athlete to express strength quickly is paramount to success. Maximum strength and rate of force development are interrelated in vitro (Andersen & Aagaard, 2006) and in vivo, where a positive relationship was found at 100 ms for rate of force development and maximum force during simple elbow flexing and extending tasks (Mirkov, Nedeljkovic, Milanovic, & Jaric, 2004). When comparing collegiate sprinters, Israetel (2013) found individuals who performed best at countermovement jumps also produced faster sprinting times and greater peak power per body mass, greater allometrically scaled peak force, and greater rate of force development at 200 ms when measured during an isometric mid-thigh pull.

Relationship Between Strength and Drop Jumping Performance

Drop jump performance is highly strength-dependent, especially at higher dropping heights (Barr & Nolte, 2014; Bassa et al., 2012). Drop jumps are unique in their ability to induce greater ground reaction forces and landing rate of force development because of the acceleration due to gravity when dropping from a height (Ebben et al., 2010). Stronger athletes not only perform better than their weaker peers at a given drop height, but also experience a smaller reduction in jump height as drop height increases suggesting that weaker athletes do not possess requisite strength to overcome higher landing forces upon impact (Barr & Nolte, 2014). Strength is a primary contributor to drop jumping performance, but drop jump performance also requires a rapid expression of strength, making drop jumps reliant on power production. Pertaining to drop jumps, stronger individuals produce maximal values of power output at higher drop heights (0.62 m) when compared to weaker individuals (0.32 m) (Matic et al., 2015).

Maximal muscular power is determined by the parameters force and velocity. Therefore, improvements in muscular power can be achieved through increasing maximal force or maximal velocity of a movement (Cormie et al., 2011). The correlations between strength/mass ratios and speed of movement are likely minimal or small when external resistance is very small as evidenced during lateral adductive arm swings (Henry & Whitley, 1960). However, as external resistance increases strength plays a more dominant role in speed of movement (Siff, 2003). If individuals achieve maximal power production at similar relative intensities, one could argue that stronger individuals require a greater load to reach maximal power production. Figure 2.1 shows a schematic created by Zatsiorsky and Kraemer (1995) depicting the idealized force-velocity curves for concentric and eccentric action. Zatsiorsky and Kraemer (1995) found that maximal dynamic power is achieved at approximately one-third of the maximal velocity and one-half of the maximal force muscles are capable of producing.

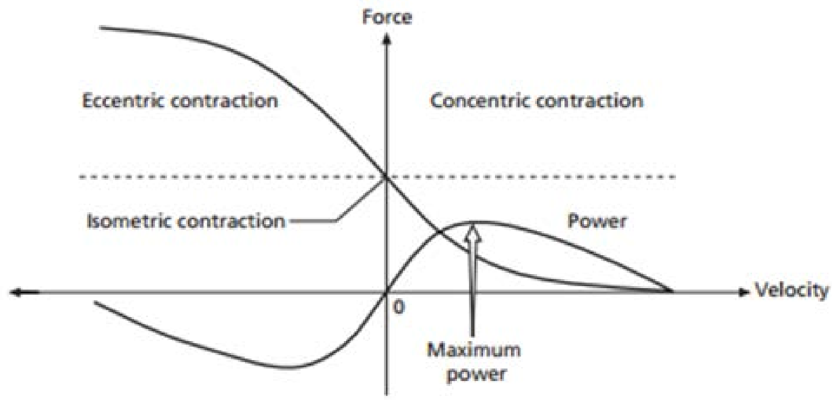

Figure 2.1 Force-velocity and power curves. Adapted from Zatsiorsky & Kraemer (1995)

The drop jump is quite different in its force-velocity characteristics (Figure 2.2) than a movement like the squat jump or a primarily concentric action because of contributions from non-contractile elements such as elastic energy, reflexive processes, and other muscle changes (Bosco et al., 1982). Bosco et al. (1982) state that studies of force-velocity curves under ballistic and non-ballistic conditions have produced similar results; confirming that traditional force-velocity curves do not describe the force-velocity relationship for plyometric muscle actions. With regard to strength's contribution to power, Perrine, Gregor, Munroe, and Edgerton (1978) observed an upward shift in the power curve following a heavy strength training intervention. Stone et al., (2003) also showed that stronger (weight-trained) individuals achieve peak power at higher percentages of their 1RM back squat than weaker individuals. These results suggest that relative load and training history affect the load at which peak power is achieved. Findings by Matic et al. (2015) corroborated this finding by showing that stronger physically active males reached maximal power production at higher dropping heights than their weaker peers. Stronger subjects also produced, on average, greater power outputs during the concentric (propulsion) phase at every drop height tested. Findings indicate that maximal strength is an important factor to consider when optimizing drop height due to the effect maximal strength has on power and explosiveness (Schmidtbleicher, 1992; Stone et al., 2003).

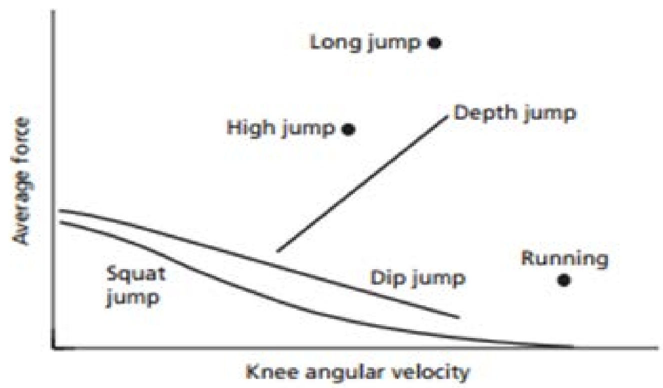

Figure 2.2 Force-velocity curve for different types of jumps and sprinting. For the drop jump force is no longer inversely proportional to the velocity of movement as is seen during the squat jump or dip (countermovement) jump. Adapted from Bosco (1982).

<u>Drop Jump as a Testing and Monitoring Tool</u>

The static jump and countermovement jump have been well explored and implemented as testing and monitoring tools in many sports (Gathercole, Sporer, Stellingwerff, & Sleivert, 2015; Hansen, Cronin, Pickering, & Douglas, 2011; Ziv & Lidor, 2010). The drop jump, however, has not received the same amount of attention in literature. The drop jump is sometimes used alongside other forms of jumping tests with each test offering insight into different qualities of performance (Ebben et al., 2010; Sheppard, et al., 2012). For example the static jump can be used to assess an athlete’s ability to jump from a starting position similar to that of an American football lineman or a weightlifter at the initiation of a snatch or clean and jerk. The countermovement jump test is popular among strength and conditioning practitioners because of its simplicity, reliability (Moir, Button, Glaister, & Stone, 2004) and similarity to multi-joint explosive movements in sport (Nuzzo, McBride, Cormie, McCaulley, 2008). The static jump and countermovement jump are often administered periodically throughout a training program to test an athlete's explosiveness; elucidating their response to training, preparedness for competition, and fatigue (Hornsby, 2013; Taylor, Chapman, Cronin, Newton, & Gill, 2012).

Although the drop jump is not as prevalent in research or practice, it has the distinction of being the most intense form of any plyometric jumping exercise (Verkhoshansky & Verkhoshansky, 2011). When compared to other forms of jumping the drop jump exhibits higher ground reaction forces and eccentric rate of force development (Ebben et al., 2010; Jensen & Ebben, 2007; Wallace et al., 2010). McBride, McCaulley, and Cormie (2008) have compared force, power, velocity, jump height, and muscle activity between static jumps, countermovement jumps, and drop jumps. Pre-activity (100 ms prior to eccentric loading) and eccentric muscle activity of the vastus lateralis and vastus medialis was significantly higher during the DJ in comparison to the SJ. Maximal jump height was significantly higher during the DJ (0.41 ± 0.05 m) and CMJ (0.40 ± 0.06 m) compared with the SJ (0.37 ± 0.07 m), but no significant difference existed between CMJ and DJ. McBride et al. (2008) attributes the increase in vertical jump performance seen in CMJ and DJ over SJ to the increased levels of pre-activity and eccentric phase muscle activity, which create a more forceful concentric muscle action. However, increases in drop height will result in increased eccentric loading, leading to a negative energy balance if the energy absorbed during the eccentric phase exceeds the energy produced during the concentric phase (Gollhofer, Strojnik, Rapp, & Schweizer, 1992).

These results suggest that the drop jump is a very intense stimulus, offering greater adaptation when performed correctly and safely. Verkhoshansky (1966) suggested that practitioners "allow these [drop] jumps only for a single-minded and systematic use on a high level of sports mastery" and warned against "an ill-advised increase in volume and utilization [of drop jumps] in the training of beginning sportsman". Verkhoshansky was apparently concerned with inexperienced athletes or coaches adopting his advanced drop jump training methods without the requisite skill or strength to perform them safely (Verkhoshansky & Verkhoshansky, 2011). Under controlled testing conditions drop jumps do not necessarily increase the probability of injury in skilled or unskilled participants (Bobbert, 1990). The risk of injury during drop jump testing or training appears unlikely when supervised by qualified scientists and coaches. However, inexperienced coaches and sport scientists are often confounded with current drop jump research due to disparities in drop height prescription, training volume, and jumping technique utilized (Walsh et al., 2004).

Influence of Drop Jumping Technique

Drop jump technique has a significant impact on the outcome of drop jump training and discrete variables of interest during testing (Bobbert, Mackay, Schinkelshoek, Huijing, & van Ingen Schenau, 1986; Bobbert et al., 1987; Walsh et al., 2004; Marshall & Moran, 2013). Bobbert et al. (1986) observed the jumping styles of thirteen handball players during drop jumps from 40 cm. Subjects were found to demonstrate one of two jumping styles: a countermovement jump style drop jump that involved a large amplitude of movement (bending hips and knees considerably before push-off) or a drop jump with a much smaller amplitude of movement and shorter push-off phase (Bobbert et al., 1986). Bobbert et al. (1987) later performed more research on the these two styles of drop jumping with regard to biomechanical differences, referring to them as countermovement drop jumps or bounce drop jumps. Results from Bobbert's research found the bounce drop jump technique exhibited larger values of moments and power output about the knee and ankle joints than countermovement drop jumps or standard countermovement jumps (Bobbert et al., 1986).

Higher velocities of eccentric actions and shorter time intervals between eccentric action and the start of concentric action are observed in bounce drop jumps as well (Bobbert, 1987). A faster eccentric action (pre-stretch) of the muscle increases the potentiation of the following concentric action. Potentiation is greater in magnitude as the speed of eccentric action increases and smaller in magnitude as time elapses following eccentric action (Cavagna et al., 1975). Using the bounce drop jump technique in an attempt to shorten ground contact time has shown to increase measures of peak force and mechanical power output (Bobbert et al., 1990, Walsh et al., 2004). However, imposing limitations on ground contact time will also result in a decreased jump height achieved (Byrne, Moran, Rankin, & Kinsella, 2010). In sports such as sprinting the bounce drop jump technique may be most appropriate because ground contact times are limited and power output takes priority – as it is associated with acceleration (Walsh et al., 2004). Barr and Nolte (2011) questioned the reactive strength index, which considers both jump height and ground contact time -as a measure of drop jump performance after finding maximal jump height to have stronger correlations with sprinting performance than reactive strength index.

Advanced athletes with fewer restrictions on time for push-off such as volleyball or basketball players may benefit more from countermovement drop jump training as this technique is more specific to their sporting movements (Walsh et al., 2004). Sport coaches should employ drop jumps that do not restrict ground contact time during training if an increase in countermovement jump performance is (Marshall & Moran, 2013). Contact times will be longer and result in a lower reactive strength measure when maximum jump height is prioritized (Young et al., 1995). Previous researchers have demonstrated that beyond physiological measures drop jumping performance depends heavily on the instructions given (Young et al., 1995), technique utilized (Bobbert et al., 1986; Bobbert et al., 1987; Marshall & Moran, 2013), drop height (Bobbert et al., 1987; Kollias et al., 2004; Matic et al., 2015), and performance measures selected (Flanagan, Ebben, & Jensen, 2008). The versatility of the drop jump makes it a wonderful tool for testing and monitoring strength, power, reactive ability, and neuromuscular function of advanced athletes (Barr & Nolte, 2014; Byrne et al., 2010; Sheppard et al., 2012; Viitasalo, Salo, & Lahtinen, 1998). Unfortunately, the drop jump's versatility has led to its misuse in practice by perplexed coaches.

<u>Prescribing Drop Jump Drop Heights</u>

Most researchers prescribe a single drop height for all subjects when certain variables such as displacement, leg stiffness, and duration of eccentric and concentric phases are being measured (Baca, 1999; Ball & Zanetti, 2012; Flanagan et al., 2008; Kollias et al., 2004). Prescribing a drop height for subjects is usually determined via maximal countermovement jump height method, also called the maximal jump height method (Byrne et al., 2014; Ebben et al., 2010, McBride et al., 2008), or the reactive strength index method (Byrne et al., 2010). Determining drop height via maximal jump height method requires the researcher or coach to set the drop height to a height equal to the subject's maximal countermovement jump height. The reactive strength index method has gained popularity because it considers not only maximal jump height but also ground contact time. Reactive strength index is calculated as follows: RSI= DJH/GCT, where DJH is maximal drop jump height in centimeters and GCT is ground contact time in seconds (Barr and Nolte, 2011). When using the reactive strength index method the drop height is set to the drop height corresponding to the greatest value (Byrne et al., 2014).

Other researchers have tested subjects' drop jumps at incrementally higher drop heights that are selected arbitrarily (Aboodarda et al., 2014; Gulick et al., 2008). Increments have been as small as 10 cm (Bassa et al., 2012) or as large as 20 cm (Walsh et al., 2004). Once data are collected the results are analyzed based on factors such as reactive strength index or maximal drop jump height to determine optimal drop height. The reactive strength index and maximal jump height methods produce different results when determining optimal drop height is desired (Ebben et al., 2010). If minimizing ground contact time and achieving higher peak power is emphasized the RSI method should be used, but this method will reduce maximal drop jump height achieved (Walsh et al., 2004). The reactive strength index method may be useful if the time-frame for jumping is critical (Feldmann et al., 2012), but overall it seems to be inferior to other methods because of the limitations imposed on the athlete, making it impossible for maximal jump height to be achieved (Ball & Zanetti, 2012). If maximal drop jump height is of primary concern there should be no limitations made on ground contact time (Walsh et al., 2004).

Drop height prescription methods affect acute performance measures, as well as long-term improvements from training. Byrne et al., (2010) found an 8 week training program using both the maximal jump height method and reactive strength index method to increase countermovement jump performance, but the maximal jump height group experienced greater improvements in reactive strength measures (i.e. RSI at 20, 30, 40, 50, and 60 cm) over the reactive strength index group. In a study conducted by Taube, Leukel, Lauber, and Gollhofer (2010) subjects were assigned to 4-week training interventions that included different drop jump training protocols. Subjects in the first intervention performed drop jumps from heights of 30, 50, and 75 cm while subjects in the second intervention performed drop jumps from 30 cm exclusively for the entire duration of the study. When comparing the results post-training Taube et al. (2010) found that both interventions made similar improvements in reactive strength index (+14%), but the first intervention experienced an increase in ground contact time. Leaukel, Taube, Gruber, Hodapp, and Gollhofer (2008) corroborated the findings of Taube (2010) when he observed an increase in the short latency component of the stretch-reflex during drop drops from excessive heights (76 cm). Leukel et al. (2008) posited that the increased latency period is a result of the decreased excitability of the H-reflex and serves as a ‘prevention strategy’ to protect the tendomuscular system from potential injuries at high loads. Both Leukal et al. (2007) and Taube et al. (2010) demonstrated the relationship between drop height and neuromuscular activity and performance.

It is apparent that normalizing drop height based on individual ability is required as current methods are insufficient in accounting for differences in strength levels and requirements of sport. Verkhoshansky and Verkhoshansky (2011) believed ground contact time is important, but that it is secondary to jump height. Verkhoshanky’s opinion is substantiated by research showing the importance of maximal drop jump height ability in athletes from various sports and its relationship with other strength and power fitness qualities (Earp et al., 2010; Ebben et al., 2010; Hunter et al., 2015; Kollias et al., 2004; Sheppard et al., 2012). The methods currently used in research and practice for prescribing optimal drop height lack consideration for the differences between athletes mentioned earlier. The author recommends using the maximal drop jump height method to determine optimal drop height in lieu of the maximal countermovement jump height (MJH) and reactive strength index methods. The maximal drop jump height method is superior to other methods because it directly measures drop jump height at various drop heights until the optimal drop height is discovered. Previous researchers have attempted to find optimal drop height via the maximal drop jump height method (Bassa et al., 2012; Byrne et al., 2010), but the methods may have been flawed because drop height was increased in rather large increments (10-20cm). This may have affected the accuracy when determining the drop height that elicited the greatest drop jump performance.

Purpose

The primary purpose of this investigation is to determine the relationship between relative 1RM back squat and optimal drop height. The second purpose is to examine the relationship between optimal drop height and countermovement jump height. Optimal drop height will be measured more precisely in this study than it has been in research to date. The results from this study will elucidate the relationships between relative lower body strength, countermovement jump performance, and optimal drop height. The rationale for this thesis is to provide practitioners within the strength and conditioning field with guidelines to make well informed individualized prescriptions of drop jump heights based on their athlete’s strength levels and countermovement jumping ability.

CHAPTER 3

RELATIONSHIP BETWEEN LOWER BODY STRENGTH, COUNTERMOVEMENT JUMP HEIGHT, AND OPTIMAL DROP JUMP DROP HEIGHT

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ABSTRACT

The purpose of this study was to understand the relationship between maximum back squat one-repetition maximum relative to body mass (1RMrel), countermovement jump height (CMJH), and optimal drop height in drop jump (DHopt). Fifteen male participants with various sport backgrounds and training experience completed a one repetition maximum (1RM) back squat, maximum countermovement jump (CMJ), and drop jumps (DJ) from incrementally increasing drop heights to determine which drop height elicited the greatest jump height. The DHopt testing protocol was unique in that smaller increments were used to determine DHopt compared to what has been reported in literature previously. Pearson correlation coefficients revealed that DHopt had small (r=0.214) and moderate (r=0.464) relationships with 1RMrel and CMJH, respectively. A second analysis (n=13) was conducted since two participants were powerlifters and identified as possibly being representative of a different population. The second analysis found that DHopt had strong relationships with 1RMrel (r=0.645) and CMJH (r=0.690). Results from this study seem to suggest that individuals with greater 1RMrel and CMJH tend to have a higher DHopt. However, this relationship may not be observed among all populations due to likely differences in sport background, genetics, and/or training experience.

INTRODUCTION

Strength and conditioning practitioners commonly employ the vertical jump as a tool for measuring an athlete's explosive strength (i.e. the ability to express force rapidly). Training and monitoring vertical jumps has become ubiquitous in practice because of their biomechanical similarities to sporting movements and their ease of administration on the field or in the lab [27]. Practitioners will often test vertical jumps periodically throughout training cycles to ascertain the power production of their athletes [23,25]. With regard to strength-power sports such as weightlifting [15] and shotput [29] vertical jumping ability is strongly associated with sport performance. In sports such as long jump or high jump, jumping ability determines competition success directly. Athletes with superior countermovement jump performances have demonstrated greater maximum running speeds [36] and greater proficiency in agility tasks requiring quick changes of direction [6,13]. Interestingly, researchers have also found strong associations between jumping ability and 3,000 – 5,000 m running performances [24]. The indisputable relationship between jumping ability and success in sport exist due to the neuromuscular qualitites they share.

Strength can be defined as the ability of the neuromuscular system to produce force against an external resistance [42], and is strongly correlated with jumping performance [15,39]. Research focusing on long-term strength training interventions have corroborated this general principle by finding that improvements in strength result in concomitant improvements in jumping ability [40,44,45]. Underlying physiological characteristics such as pennation angle, fascicle length, fiber type, and stiffness of the musculo-tendon units have strong influences on the force producing ability of an athlete [12,17]. Improvements in these physiological characteristics, along with neurological adaptations to training improve the athlete's mechanical efficiency [26] and power production [34]. This means stronger, more experienced athletes are capable of utilizing the stored elastic energy developed during the eccentric (loading) phase of a jump more efficiently than weaker athletes, enabling greater force production during the subsequent concentric (push-off) phase of a jump [11,32]. Stronger individuals also produce greater power during loaded countermovement jumps and static jumps up to 90% of their one repetition maximum (1RM) back squat [40]. Maximal strength contributes greatly to explosiveness [41] and seems to play a greater role in power production as the external resistance increases [38].

Although a preponderance of evidence exist demonstrating strength's relationship with loaded and unloaded countermovement jumps and static jumps [23,31,40] literature examining strength's relationship with drop jump performance is limited. Greater ground reaction force, eccentric rate of force development, and mechanical loading have been observed in drop jumps when compared to other vertical jumping tasks [18,47]. Barr & Nolte (2014) found stronger individuals to perform better than weaker individuals at any given drop height. Stronger individuals also experienced a smaller reduction in jump height as drop height increased, suggesting that weaker individuals did not possess requisite strength to handle the higher landing forces induced from greater drop heights [7]. Stronger individuals not only jump higher from greater drop heights, they also require a greater drop height to reach maximal power output (0.62 m) than weaker individuals (0.32 m) [16].

Researchers and coaches alike appear to have difficulty in selecting appropriate drop heights for their subjects or athletes. Researchers often adopt a single height for subjects to drop from when certain variables are being measured [3,5,20]. Other researchers have tested subjects at incrementally higher drop heights to determine which drop height elicits the greatest jump height or power output [1,21]. Heights have been increased by as little as 10 cm [8] or as much as 20 cm [48] in previous research. It is the opinion of the author that these increments are too great and that the optimal drop height undoubtedly lies somewhere in between such large increments. The method by which optimal drop height is determined also influences testing results. If the practitioner is concerned with minimizing ground contact time (GCT) or observing higher peak power the reactive strength index (RSI) should be used, but this method will reduce the maximal drop height [48] and maximal jump height achieved [5]. Reactive strength index is calculated as follows: RSI = DJ JH/GCT, where drop jump jump height (DJ JH) is measured in centimeters and ground contact time (GCT) in seconds. Alternatively, if maximal DJ JH is of primary concern there should be no limitations made on GCT [48]. Another method is the maximal drop jump height method. Although the RSI and maximal drop jump height methods both require the subject to jump from various drop heights, only the RSI method places restrictions on GCT. Optimal drop height is equal to the drop height eliciting the greatest RSI value when using the RSI method and equal to the drop height eliciting the greatest jump height when using the maximal drop jump height method. Verkhoshansky (2011) also believed that GCT is secondary to maximal jump height when administering drops jumps [46].

The originator of the drop jump, Dr. Yuri Verkhoshansky, considers the drop jump to be the most intense form of any plyometric jumping exercise [45]. For this reason Verkhoshansky reserved the drop jump for only his most advanced athletes and warned against an “ill-advised increase in volume and utilization [of drop jumps] in the training of beginning sportsmen” [8]. Today, coaches and sports scientists are confounded with current research pertaining to drop jumps due to disparities in drop height prescription, training volume, and jumping technique utilized [47]. When testing or training athletes, coaches will often choose a single drop height for an entire group to drop from, without considering the differences in strength, training experience, or jumping ability among athletes. The National Strength and Conditioning Association recommends a drop height no higher than 46 cm. (18 in) for athletes weighing more than 100 kg (220 lbs) [4], disregarding strength as a factor in drop jumping ability. Practices like these defy basic training principles such as individualization and specificity. Sport science practitioners must accurately prescribe optimal drop heights based on the neuromuscular fitness of each athlete. Therefore, the primary purpose of this study was to understand the relationship between relative lower body strength and optimal drop height. The secondary purpose was to understand the relationship between optimal drop height and maximal countermovement jump height. The outcome of this study was intended to aid sport science practitioners and coaches in more accurately prescribing optimal drop heights in the future.

METHODS

Experimental Approach to the Problem

Subjects attended the Sport and Exercise Science Laboratory at East Tennessee State University on three separate occasions to participate in a familiarization session, one repetition maximum (1RM) back squat testing session, and maximal countermovement jump and drop jump testing session. Subjects underwent a series of drop jumps from various heights in addition to back squat 1RM and maximum countermovement jump height measurements. Relationships of optimal drop height (DHopt) with relative back squat 1RM (1RMrel) and maximum countermovement jump height (CMJH) were quantified as correlation coefficients.

Subjects

Fifteen male subjects (n=15) volunteered to participate in this study. Subjects had experience in powerlifting (n=2), weightlifting (n=4), shotput (n=1), distance running (n=1), and cycling (n=1). Other subjects (n=6) resistance trained for recreational purposes only (e 1 session per week) (Table 3.1). Inclusion criteria for this study required subjects to: have been injury-free for at least six months, have at least six months of consistent back squat training experience, be male, and be between the ages of 18 and 28 years old. Only male subjects were tested to account for differences between sexes. Subjects' back squats were observed during the familiarization session to ensure that a knee flexion angle no greater than 90 degrees was achieved at the bottom of the squat. Subjects were excluded if they were unable to meet these requirements. All subjects read and signed written informed consent documents as approved by the University's Institutional Review Board.

Procedures

Familiarization Session

The familiarization session was conducted approximately 48-96 hours prior to 1RM back squat testing. The content of the familiarization session included measures of standing height using an electronic stadiometer (Cardinal Scale, model DHRWM, Webb City, MO) and body mass using a calibrated digital scale certified to the nearest 0.1 kg (Tanita BF-350, Arlington Heights, IL). Subjects reported an estimated 1RM back squat as well as previous experience with back squatting, countermovement jumping, and drop jumping during the familiarization session (Table 3.1). Subjects underwent a warm-up protocol (Table 3.2) at the beginning of each session. Following a general warm-up subjects executed back squats for two sets of five repetitions with a 20 kg bar. The primary investigator observed these squats to ensure that a knee flexion angle no greater than 90 degrees was achieved at the bottom position of the squat. Knee angles were measured using a manual goniometer. The appropriate height for the squat rack safety pins was determined for each subject. Subjects then performed a minimum of two and a maximum of four countermovement jumps (CMJ) at 50% and 75% intensity. Subjects were given extra CMJ attempts if they were unable to execute the movement with an upright posture or if they appeared to be jumping horizontally. Following CMJ familiarization, two to four DJs were performed between 50% and 75% intensity at drop heights of 30 cm, 40 cm, and 50 cm. Although the DJs were performed at submaximal intensities during the familiarization session, subjects were given the following instructions: 1) jump as high as possible while spending the least amount of time possible in contact with the ground [14], 2) create tension in the lower body and anticipate the landing by flexing the hips, knees, and ankles prior to impact [33], and 3) step straight out from the box (to avoid elevating or lowering the center of mass (COM)). These instructions were also given during the maximal DJ testing session with emphasis being placed on "jumping as high as possible". Subjects were told to place a polyvinyl chloride (PVC) pipe (0.1 kg) on their back at approximately the C7 vertebrae to prevent contribution from arm swing during CMJ and DJ [49].

Table 3.1 Participant descriptive data (n=15)

Descriptive measure	**Mean ± SD**
Age (yrs)	25.4 ± 2.8
Height (cm)	175.7 ± 6.1
Body mass (kg)	85.3 ± 14.7
Years BS	7.6 ± 4.7
Years CMJ	4.7 ± 5.1
Years DJ	1.8 ± 3.0

Note: BS = back squat; CMJ = countermovement jump; DJ = drop jump.

Table 3.2. Warm-up procedures

1. Cycle ergometer set at 50 W – 70 rpm for 2 minutes
2. 25 jumping jacks
3. 10 bodyweight squats
4. 10 bodyweight walking lunges
5. 10 bodyweight side lunges
6. 10 goodmornings

One Repetition Maximum Back Squat Testing Session

The one repetition maximum (1RM) back squat testing session commenced with a general dynamic warm-up (Table 3.2) followed by a back squat warm-up. The back squat warm-up consisted of seven repetitions with a 20 kg bar, five repetitions at 50%, three repetitions at 70%, two repetitions at 80%, one repetition at 90%, and one repetition at 95% of their self-estimated 1RM. Subjects were given 2.5 minutes of recovery prior to each warm-up set and four minutes of recovery prior to each 1RM attempt. The primary investigator and research assistant selected the load for subsequent 1RM attempts after each successful 1RM attempt. Loads were increased by a minimum of 2 kg following successful attempts. 1RM back squat attempts were deemed unsuccessful when the subject was unable to return to an upright position. Subjects achieved their 1RM back squat in seven attempts or less. The use of a weightlifting belt and knee sleeves was permitted. Knee wraps and squat suits were prohibited. Relative 1RM (1RMrel) was calculated as 1RM back squat divided by body mass.

Maximal Countermovement Jump and Drop Jump session

Maximal CMJs and DJs were collected between 48 and 96 hours following the 1RM back squat testing session. All jumps were performed inside of a squat rack outfitted with dual uniplanar force plates (0.91 m x 0.91 m; Rice Lake Weighing Systems, Rice Lake, WI, USA) with a sampling frequency of 1,000 Hz. Subjects began the CMJ and DJ testing session with the general dynamic warm-up (Table 3.2) used in previous sessions. CMJ testing began with a warm-up consisting of one jump at 50% and 75% of maximal effort. Thirty seconds of recovery were allowed between each submaximal jump and maximal jump. Subjects were instructed to step onto the middle of the force plates and stand still. They were given the command “3-2-1 jump!” for each attempt. Subjects completed between two and four maximal CMJ attempts. The two highest jumps within 2 cm of each other were averaged for statistical analysis. Most subjects required three maximal CMJ attempts to meet the criterion. No more than four attempts were allowed in order to prevent excessive fatigue that might hinder performance in DJ testing. A five minute recovery period was given between CMJ and DJ testing.

Wooden boxes of 30 cm and 50 cm height were fabricated by the primary investigator for DJ testing. Boards of 2.5 cm thickness were inserted under the boxes to adjust drop heights. Subjects began DJ testing with one submaximal jump at 50% and 75% effort from a drop height of 30 cm. Subjects were instructed to step onto the box and stand still before each attempt (Figure 3.1). They were then given the command “3-2-1 jump!”. Subjects began maximal DJ trials at a drop height of 30 cm. Between two and four attempts were given at each height. Drop height was increased to 40 cm following attempts at 30 cm. The drop height was increased to 50 cm if the average jump height was greater at 40 cm drop height than it was at 30 cm drop height. Drop height was increased by 10 cm if the jump height at a current drop height was greater than the jump height at the previous drop height. Drop height continued to increase by 10 cm until the subject’s jump height began to diminish. Once jump height began to diminish, the drop height was lowered by 2.5 cm increments until jump heights were recorded for each drop height falling between the two previous heights. The drop height that elicited the highest jump height was deemed optimal drop height (DHopt). The two highest recorded jumps at each height were averaged for statistical analysis. The two highest jumps had to be within 2 cm of each other to be included in analysis. Most subjects required three attempts at each drop height to meet the criteria. However, no more than four attempts were allowed at each drop height to prevent excessive fatigue. All jump data were analyzed using LabView software (ver. 2010, National Instruments, Austin, TX, USA).

Figure 3.1 DJ testing set-up

Statistical Analyses

Shapiro-Wilks normality test was used to determine if the data were normally distributed. Z-scores were calculated to identify outliers (z-scores e 2.58) within each performance variable as proposed by Tabachnick and Fidell [43]. Intraclass correlation coefficients (ICCs) and coefficients of variation (CVs) were calculated for the two highest countermovement jumps and the two highest drop jumps at DHopt to determine test-retest reliability. Pearson product-moment correlations were calculated to determine the relationship between optimal drop height (DHopt) and relative 1RM back squat (1RMrel) as well as DHopt and maximal countermovement jump height (CMJH). Hopkins (2002) has set correlation thresholds as r = 0.0 (trivial); 0.1 (small); 0.3 (moderate); 0.5 (strong); 0.7 (very strong); 0.9 (nearly perfect); and 1.0 (perfect) [22]. The level of significance was set at *pd* 0.05. Statistical analyses were conducted using Statistical Practice for Social Sciences software (Version 22, IBM Co., NY, USA) and Microsoft Excel 2013 (Microsoft, Redmond, WA, version 15.04711.1000).

RESULTS

All subjects were able to complete testing for this study with no reported injuries. Descriptive data shows that subjects had less experience with DJ (1.82 ± 2.97 yrs) compared to CMJ (4.67 ± 5.14 yrs) and BS (7.60 ± 4.65 yrs) (Table 3.1). Descriptive data from performance testing results demonstrate a large range and standard deviation in DHopt at the 0.05 alpha level (Table 3.3). Visual inspection of skewness and kurtosis and results from Shapiro-Wilks test indicated that the data were normally distributed for each performance variable measured ($p > 0.05$). Intraclass correlation coefficients for CMJH trials and drop jump jump height at DHopt were 0.99 and 0.98, respectively. The CMJH trials and drop jump jump height at DHopt also demonstrated within-individual variation with coefficients of variation of 1.44% and 2.79%, respectively.

Table 3.3 Summary of testing results (n=15)

Performance measure	**Mean ± SD**
Optimal drop height (cm)	55.7 ± 18.0
Relative 1RM back squat	1.9 ± 0.38
CMJ height (cm)	37.2 ± 5.9

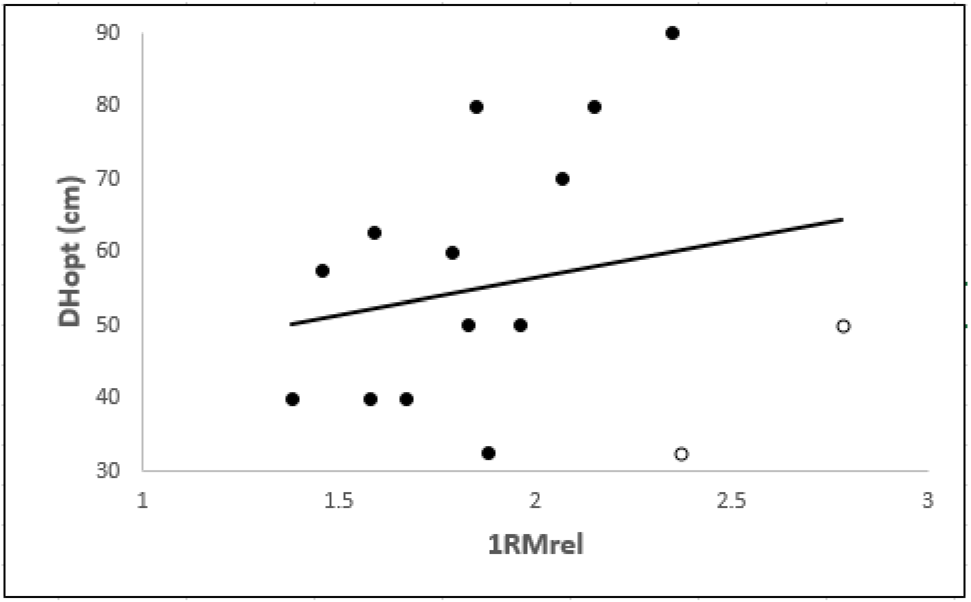
Pearson product-moment correlations (Table 3.4) indicated that there was a small correlation between 1RMrel and DHopt (r = 0.214) and a moderate correlation between CMJH and DHopt (r = 0.464). These results show 1RMrel and CMJH can account for 4.5% and 21.5% of the variance in DHopt, respectively. Two cases appeared to be separate from the rest of cases during visual inspection of a DHopt-1RMrel scatter plot (Figure 3.2). These two cases demonstrated the highest 1RMrel performances but below average DHopt results. While the subject's z-scores (-0.31 and -1.30 for DHopt and 2.28 and 1.20 for 1RMrel, respectively) did not suggest them to be outliers, further examination of the data revealed that these cases had one thing in common – they were the only powerlifters included in this study. We hypothesized that data collected from the powerlifters might represent a population incongruent with the rest of the population. This concern necessitated further analyses with the two cases excluded.

Table 3.4 Correlations among performance measures (n=15)

	DHopt	**1RMrel**	**CMJH**
DHopt	1.00		
1RMrel	0.214	1.00	
CMJH	0.464	0.620	1.00

Note: DHopt = optimal drop height; 1RMrel = relative one-repetition maximum back squat; CMJH = countermovement jump height

Figure 3.2 Scatter plot with line of best fit for relative 1RM back squat (1RMrel) and optimal drop height (DHopt) results. Unfilled circles indicate cases suspected to be from a different population (i.e. powerlifters) than the rest.



The second analysis appeared to have led to an increase in mean DHopt and a decrease in mean 1RMrel results once the powerlifter's data were omitted (Table 3.5). The relationship between DHopt and 1RMrel improved to strong (r=0.645) and the relationship between DHopt and CMJH improved to almost very strong (r=0.69) (Table 3.6). The strength of these correlations indicates that 1RMrel and CMJH can account for 41.6% and 47.6% of the variance in DHopt, respectively. The second scatterplot (Figure 3.3) reflected these relationships with a more desirable trend line and data points nearer to it.

Table 3.5 Summary of testing results without powerlifters (n=13)

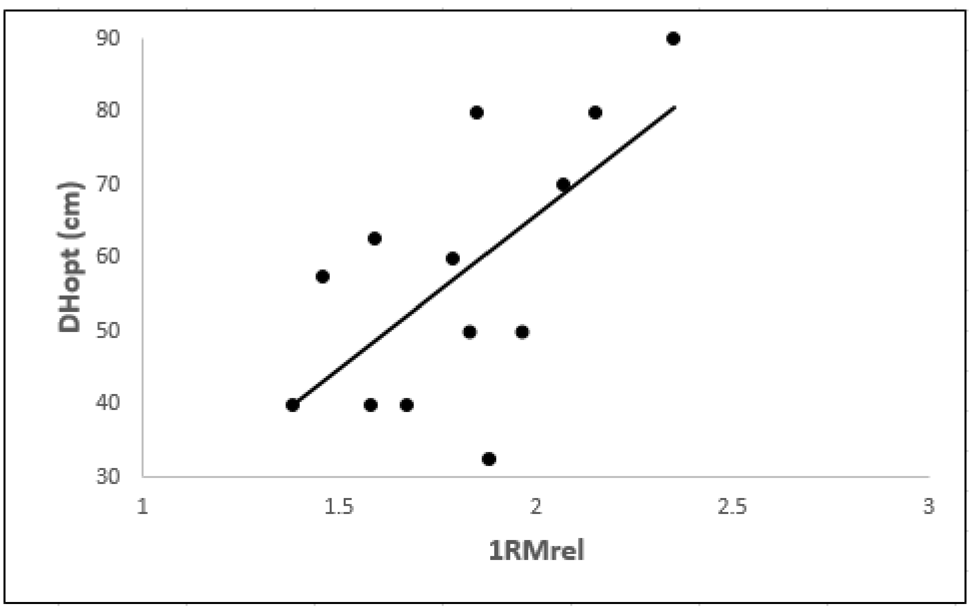
Performance measure	**Mean ± SD**
Optimal drop height (cm)	57.9 ± 18.1
Relative 1RM back squat	1.8 ± 0.3
CMJ height (cm)	36.5 ± 6.0

Table 3.6 Correlations among performance measures (n=13)

	DHopt	**1RMrel**	**CMJH**
DHopt	1.00		
1RMrel	0.65	1.00	
CMJH	0.69	0.67	1.00

Note: DHopt = optimal drop height; 1RMrel = relative one-repetition maximum back squat; CMJH = countermovement jump height

Figure 3.3 Scatter plot with line of best fit for relative 1RM back squat (1RMrel) and optimal drop height (DHopt) excluding powerlifter's data.



DISCUSSION

The purpose of this study was to understand the relationships between 1RMrel, CMJH, and DHopt. The results from this study revealed that the relationships between 1RMrel, CMJH, and DHopt might depend on the type of athlete and training background.

Initial analyses showed that DHopt had a small relationship with CMJH and a moderate relationship with 1RMrel (Table 3.4). The stronger relationship observed between DHopt and 1RMrel compared to DHopt and CMJH might be indicative of a greater contribution from strength rather than CMJH in the variance explaining DHopt. The small relationship between DHopt and CMJH was surprising considering the DJ technique employed in this study was similar to the countermovement jump style DJ employed by Bobbert et al. [11]. The countermovement jump style DJ allows unlimited GCT, resulting in greater DJ height [10] and higher DHopt [14] compared to the bounce jump style DJ which limits GCT (usually 200-260 ms). Matic (2015) also found a moderate relationship between relative maximal back squat and optimum drop height. However, Matic (2015) defined optimum drop height as the drop height at which maximum power output was achieved and placed limitations on GCT (<400 ms) during DJ testing [30]. Previous studies have found reductions in optimal drop height and maximal DJ height when GCT is limited [11]. Barr (2014) observed an increase in strength of correlation from small ($r = 0.28$) to large ($r = 0.56$) between maximal DJ height and 1RMrel as drop height increased from 0.24 m to 0.84 m without limiting GCT [7]. The current study placed no limitations on GCT and emphasized maximal DJ height similar to Barr (2014).

However, the second analysis of the current study was conducted because visual examination of the scatter plot (Figure 3.1) suggested the potential presence of two different samples (i.e. powerlifters vs. non-powerlifters). The second analysis, completed with powerlifters excluded, yielded strong relationships between all performance measures (Table 3.6). Since the relationships were stronger between performance variables following the exclusion of Powerlifters, we can hypothesize that training background has an influence on the relationship between 1RMrel, CMJH, and DHopt. This hypothesis is partially supported by previous research that found DJ performance varied by a statistically significant amount between athletes of different sports; track and field athletes and volleyball players jump higher than handball players and rowers from a drop height of 60 cm [28]. As observed in this study, the reported DHopt differences could have also been due to disparities in maximal strength.

Although a plethora of research exists demonstrating strong relationships between jumping performance and maximal strength measures [15,23,25,35], strength alone cannot account for all variance in jump performance. Alkjaer (2013) observed statistical improvements in DJ performance following four weeks of intensive DJ training in the absence of any changes in maximal strength. These improvements were attributed to neural factors that regulate activation patterns (e.g. enhanced efferent motor output and neuron excitability) [2]. While most athletes in strength-power, strength-speed, or even endurance sports employ plyometric movements in training or competition, powerlifters typically train at high loads specific to the demands of competition, resulting in very low movement velocities and presumably limited use of the stretch-shortening cycle. We speculate that the powerlifters' relatively poor DHopt performances despite high 1RMrel can be ascribed to sport-specific training practices with limited plyometric movements.

The current study's sample can be considered heterogeneous, consisting of powerlifters, weightlifters, distance runners, a cyclist, a shotputter, and other recreational weight-trained males. Although strong relationships were observed in the second analysis, it is possible that the relationships could have been stronger in the initial analysis if the subjects had similar training backgrounds. It is also possible that the powerlifters recruited in this study were individuals genetically predisposed to developing high levels of strength but low levels of stretch-shortening cycle function. Therefore, the powerlifters in this study might not be representative of all powerlifters. In either case, the results of the second analysis suggest that coaches should be aware of athletes whose DHopt is not well reflected in 1RMrel since DHopt is determined by innumerable neuromuscular components not explored presently.

In addition to the main findings of the present study, it was observed that 13 of 15 subjects achieved DHopt at drop heights greater than their CMJH. Initial analysis found DHopt to be approximately 19 cm higher than CMJH when maximal DJ height is used to determine DHopt. The mean DHopt of 55.66 cm found in the present study is also much higher than the DHopt of 40 cm often reported in literature [9,11,37]. Therefore, it seems unlikely that DHopt is equal to CMJH as some researchers have suggested [14,18]. The findings of this study suggest that athletes choosing a single drop height for all athletes should be avoided since DJ performance varies among different sports [16, 28].

While the present study reported statistically significant correlations, the results should be interpreted with caution. First, familiarity with DJ was low among subjects. Most subjects reported no prior experience with DJ training. Second, the participants of the present study had different sport backgrounds. Further research should seek to replicate the methods used in this study with a more homogenous group of subjects, preferably athletes within the same sport and with similar levels of maximal lower body strength, jumping ability, and DJ experience. Third, the present study included only 13 subjects after the elimination of two powerlifters. Further research should be conducted with more subjects to improve statistical power.

Additionally, the design of this study necessitated a larger number of jumps for subjects with greater DHopt. The testing protocol required every subject to begin maximal DJ attempts at 30 cm and move up incrementally. For this reason subjects with higher DHopt completed almost 30 DJ attempts during DHopt testing and reported feeling fatigued. It is also possible that 30 seconds of rest between attempts may be insufficient for full recovery during a large number of DJ attempts. The authors recommend modifying the testing methods to include longer rest periods between attempts, and repeat testing at DHopt for those athletes experiencing fatigue during testing.

CONCLUSION

This study aimed to determine the relationship of DHopt with 1RMrel and CMJH performance. The results of this study indicate that DHopt can have a strong association with 1RMrel and CMJH depending on the type of athlete or training background. Individuals with greater relative lower body strength and CMJH tended to have higher DHopt. Correlations were much weaker across all variables during the initial analyses that included powerlifters. We hypothesize that the powerlifters' comparatively low DHopt is attributed to their training practices, which likely exclude plyometric training, and/or a genetic predisposition to poor stretch-shortening cycle function. We also observed that DHopt appeared much higher in this study than in previous studies. It is possible that the higher DHopt found in this study is a result of using stronger and/or more explosive subjects. The method of using smaller increments to adjust drop height during testing likely produced higher DHopt as well. This observation suggests further research to determine DHopt is needed. The present study found that DHopt is strongly associated with CMJH and 1RMrel. However, considerations must be made for sport background and previous training experience of athletes when prescribing DHopt.

PRACTICAL APPLICATIONS

A simple 1RM back squat and CMJ test will likely reveal many differences among athletes' strength and force producing capabilities. Relative one repetition maximum back squat and CMJH have strong associations with DHopt and can be used to loosely predict DHopt, but these performance measures are incapable of accurately predicting DHopt on their own. Coaches are recommended to test each athlete's DHopt individually for future training and monitoring purposes.

REFERENCES

1. Aboodarda, J. S., Byrne, M. J., Samson, D. M., Wilson, H. B., Mokhtar, G. A., & Behm, G. D. (2014). Does performing drop jumps with additional eccentric loading improve jump performance? *Journal of Strength and Conditioning Research, 28*(8), 2314-2323.

2. Alkjaer, T., Meyland, J., Raffalt, P. C., Lundbye-Jensen, J., & Simonsen, E. B. (2013). Neuromuscular adaptations to 4 weeks of intensive drop jump training in well-trained athletes. *Physiological Reports*, *1*(5)

3. Baca, A. (1999). A comparison of methods for analyzing drop jump performance. *Medicine and Science in Sports and Exercise, 31*(3), 437.

4. Baechle, T. R., & Earle, R. W. (2008). Essentials of Strength and Conditioning (T. R. Baechle & R. W. Earle Eds. 3rd ed.): Human Kinetics.

5. Ball, N., & Zanetti, S. (2012). Relationship between reactive strength variables in horizontal and vertical drop jumps. *Journal of Strength and Conditioning Research, 26*(5), 1407-1412.

6. Barnes, L. J., Schilling, K. B., Falvo, J. M., Weiss, W. L., Creasy, K. A., & Fry, C. A. (2007). Relationship of jumping and agility performance in female volleyball athletes. *Journal of Strength and Conditioning Research, 21*(4), 1192-1196.

7. Barr, M., & Nolte, V. (2014). The importance of maximal leg strength for female athletes when performing drop jumps. *Journal of Strength and Conditioning Research, 28*(2), 373-380.

8. Bassa, E. I., Patikas, D., Panagiotidou, A. I., Papadopoulou, S. D., Pylianidis, T. C., & Kotzamanidis, C. M. (2012). The effect of dropping height on jumping performance in

trained and untrained prepubertal boys and girls. *Journal of Strength and Conditioning Research, 26*(8), 2258-2264.

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

10. Bobbert, M. F., Huijing, P. A., & van Ingen Schenau, G. J. (1987). Drop Jumping. II. The influence of dropping height on the biomechanics of drop jumping. *Medicine & Science in Sports & Exercise, 19,* 339-346.

11. Bobbert, M. F., Mackay, M., Schinkelshoek, D., Huijing, P. A., & van Ingen Schenau, G. J. (1986). Biomechanical analysis of drop and countermovement jumps. *European Journal of Applied Physiology and Occupational Physiology, 54,* 566-573.

12. Bojsen-Moller, J., Magnusson, S., Kjaer, M., & Aagaard, P. (2005). Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures. *Journal of Applied Physiology.*

13. Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport: a review of resistance training studies.(Report). *Sports Medicine, 38*(12), 1045.

14. Byrne, P., Moran, K., Rankin, P., & Kinsella, S. (2010). A comparison of methods used to identify optimal drop height for early phase adaptations in depth jump training. *Journal of Strength and Conditioning Research, 24*(8), 2050-2055.

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

16. Coh, M., & Mackala, K. (2013). Differences between the elite and subelite sprinters in kinematic and dynamic determinations of countermovement jump and drop jump. *Journal of Strength and Conditioning Research*, 27(11), 3021-3027.

17. Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power: part 1 - Biological basis of maximal power production. *Sports Medicine*, *41*(1), 17.

18. Ebben, W. P., Fauth, M., Kaufmann, C. E., & Petushek, E. (2010). Magnitude and rate of mechanical loading of a variety of exercise modes. *Journal of Strength and Conditioning Research*, *24*(1), 213-217.

19. Ferreira, L. C., Weiss, L., Hammond, K., & Schilling, B. (2010). Structural and functional predictors of drop vertical jump. *Journal of Strength and Conditioning Research*, *24*(9), 2456-2467.

20. Flanagan, E., Ebben, W. P., & Jensen, R. (2008). Reliability of the reactive strength index and time to stabilization during depth jumps. *Journal of Strength and Conditioning Research*, *22*(5), 1677-1682.

21. Gulick, D. T., Fagnani, J., Long, M., Morris, K., Hartzell, B., & Epler, M. (2008). Parameters that influence vertical jump height. *The Sport Journal*, *11*(3).

22. Hopkins, W. (2002, August 7, 2006). A new view of statistics. Retrieved from http://www.sportsci.org/resource/stats/

23. Hornsby, W. G., III. (2013). *A Systematic Approach to the Monitoring of Competitive Weightlifters.* Thesis (Ph.D.) East Tennessee State University, 2013., Johnson City, Tenn.

24. Hudgins, T. B., Scharfenberg, M. J., Triplett, M. N., & McBride, M. J. (2013). Relationship between jumping ability and running performance in events of varying distance. *Journal of Strength and Conditioning Research, 27*(3), 563-567.

25. Israetel, M. A. (2013). *The Interrelationships of Fitness Characteristics in Division 1 Athletes.* Thesis (Ph.D.) East Tennessee State University, 2013., Johnson City, Tenn.

26. Karlsen, T., Helgerud, J., Støylen, A., Lauritsen, N., & Hoff, J. (2009). maximal strength training restores walking mechanical effeciency in heart patients. *International Journal of Sports Medicine*, 30(5), 337-342.

27. Klavora, P. (2000). Vertical-jump tests: a critical review. *Strength and Conditioning Journal., 22*(5), 70.

28. Kollias, I., Panoutsakopoulos, V., & Papaiakovou, G. (2004). Comparing jumping ability among athletes of various sports: vertical drop jumping from 60 centimeters. *Journal of Strength and Conditioning Research, 18*(3), 546-550.

29. Kyriazis, T. A., Terzis, G., Boudolos, K., & Georgiadis, G. (2009). Muscular power, neuromuscular activation, and performance in shot put athletes at preseason and at competition period. *Journal of Strength and Conditioning Research, 23*(6), 1773-1779.

30. Matic, S. M., Pazin, R. N., Mrdakovic, D. V., Jankovic, N. N., Ilic, B. D., & Stefanovic, L. J. D. (2015). Optimum drop height for maximizing power output in drop jump: the effect of maximal muscle strength. *Journal of Strength and Conditioning Research, 29*(12), 3300-3310.

31. McBride, J.M, Triplett-McBride, T., Davie, Allan, Newton, R.U.. (1999). A comparison of strength and power characteristics between power lifters, olympic lifters, and sprinters. *Journal of Strength and Conditioning Research, 13*(1), 58.

32. McBride, J. M., & Snyder, J. G. (2012). Mechanical efficiency and force–time curve variation during repetitive jumping in trained and untrained jumpers. *European Journal of Applied Physiology*, *112*(10), 3469.

33. McBride, M. J., McCaulley, O. G., & Cormie, O. P. (2008). Influence of preactivity and eccentric muscle activity on concentric performance during vertical jumping. *Journal of Strength and Conditioning Research*, *22*(3), 750-757.

34. Paavolainen, L., Hakkinen, K., Hamalainen, I., Nummela, A., & Rusko, H. (2003). Explosive- strength training improves 5-km running time by improving running economy and muscle power. *Scandinavian Journal of Medicine & Science in Sports*, *13*(4), 272-272.

35. Ramsey, M., Kavanaugh, A., Israetel, M., Swisher, A., Nelson, C., & Stone, M. (2011). Changes in relationship between static jump height, strength characteristics, and body composition with training. *Medicine and Science In Sports And Exercise*, *43*(5).

36. Robbins, W. D., & Young, B. W. (2012). Positional relationships between various sprint and jump abilities in elite american football players. *Journal of Strength and Conditioning Research*, *26*(2), 388-397.

37. Ruan, M., & Li, L. (2008). Influence of a horizontal approach on the mechanical output during drop jumps. *Research Quarterly for Exercise and Sport*, *79*(1), 1.

38. Schmidtbleicher , D. (1992). *Training for Power Events. In: Strength and Power in Sport.* Oxford, UK.

39. Shedlarski, A. (2011d). *The Relationship of Strength and Body Composition to Vertical Jump Ability in Division 1 Female Volleyball Players.* Thesis (Undergraduate Honors)--East Tennessee State University, 2011., Johnson City, Tenn.

40. Sheppard, J. M., Nolan, E., & Newton, R. U. (2012). Changes in strength and power qualities over two years in volleyball players transitioning from junior to senior national team. *Journal of Strength and Conditioning Research, 26*(1), 152.

41. Stone, M., O'Bryant, H., McCoy, L., Coglianese, R., Lehmkuhl, M., & Shilling, B. (2003). power and maximum strength relationships during performance of dynamic and static weighted jumps. *Journal of Strength and Conditioning Research*, 17(1).

42. Stone, M. H., Stone, M., & Sands, W. A. (2007). *Principles and Practice of Resistance Training.* Champaign, IL: Human Kinetics.

43. Tabachnick, B., & Fidell, L. (2007). *Experimental Design Using ANOVA*. Belmont, CA: Thompson Brooks/Cole.

44. Terzis, G., Georgiadis, G., Vassiliadou, E., & Manta, P. (2003). Relationship between shot put performance and triceps brachii fiber type composition and power production. *European Journal of Applied Physiology, 90*(1-2), 10.

45. Thomas, T. R., Zebas, C. J., Bahrke, M. S., Araujo, J., & Etheridge, G. L. (1983). Physiological and psychological correlates of success in track and field athletes. *British Journal of Sports Medicine, 17*(2), 102.

46. Verkhoshansky, Y., & Verkhoshansky, N. (2011). *Special Strength Training; Manual for Coaches*. Rome, Italy: Verkhoshansky SSTM.

47. Wallace, J. B., Kernozek, W. T., White, M. J., Kline, E. D., Wright, A. G., Peng, A. H.-T., & Huang, A. C.-F. (2010). Quantification of vertical ground reaction forces of popular bilateral plyometric exercises. *Journal of Strength and Conditioning Research, 24*(1), 207-212.

48. Walsh, M., Arampatzis, A., Schade, F., & Bruggemann, G. P. (2004). The effect of drop jump starting height and contact time on power, work performed, and moment of force. *Journal of Strength and Conditioning Research, 18*(3), 561-566.

49. Walsh, S. M., Böhm, M. H., Butterfield, M. M., & Santhosam, M. J. (2007). Gender bias in the effects of arms and countermovement on jumping. *Journal of Strength and Conditioning Research*, *21*(2), 362-366.

CHAPTER 4

SUMMARY AND FUTURE DIRECTIONS

This study aimed to determine the relationship of optimal drop jump drop height with relative one repetition maximum back squat and countermovement jump height performance. The results of this study indicate that DHopt can have a strong association with 1RMrel (r=0.645, N=13) and CMJH (r=0.690, N=13) depending on the type of athlete or training background. Individuals with greater relative lower body strength and CMJH tended to have higher DHopt overall. Correlations were much weaker across all variables during the initial analyses that included powerlifters. We hypothesize that the powerlifters' comparatively low DHopt is attributed to their training practices, which likely exclude plyometric training, and/or a genetic predisposition to poor stretch-shortening cycle function. We also observed that DHopt appeared much higher in this study than in previous studies. It is possible that the higher DHopt found in this study is a result of using stronger and/or more explosive subjects. The method of using smaller increments to adjust drop height during testing likely produced higher DHopt as well. This observation suggests further research on methods to determine DHopt is needed.

While the present study reported statistically significant correlations, the results should be interpreted with caution. First, familiarity with DJ among athletes was low. Most subjects reported no prior experience with DJ training. Second, the participants of the present study had different sport backgrounds. Further research should seek to replicate the methods used in this study with a more homogenous group of subjects, preferably athletes within the same sport and with similar levels of maximal lower body strength, jumping ability, and DJ experience. Third, the present study included 13 subjects after the elimination of two powerlifters. Further research should be conducted with more subjects to improve statistical power.

Last, the design of this study necessitated a larger number of jumps for subjects with greater DHopt. Testing protocol required every subject to begin maximal DJ attempts at 30 cm and move up incrementally. For this reason subjects with higher DHopt completed almost 30 DJ attempts during DHopt testing and reported feeling fatigued. It is also possible that 30 seconds of rest between attempts may be insufficient for full recovery during a large number of DJ attempts. The authors recommend modifying the testing methods to include longer rest periods between attempts and repeat testing at DHopt after a long recovery period for those athletes experiencing fatigue during testing. Coaches are recommended to test each athlete’s DHopt individually for future training, monitoring, and testing purposes.

REFERENCES

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Dyhre-Poulsen, P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *Journal of Applied Physiology*, 93(4), 1318-1326.

Aboodarda, J. S., Byrne, M. J., Samson, D. M., Wilson, H. B., Mokhtar, G. A., & Behm, G. D. (2014). Does performing drop jumps with additional eccentric loading improve jump performance? *Journal of Strength and Conditioning Research*, *28*(8), 2314-2323.

Andersen, L. L., & Aagaard, P. (2006). Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *European Journal of Applied Physiology 96*(1), 46-52.

Baca, A. (1999). A comparison of methods for analyzing drop jump performance. *Medicine and Science in Sports and Exercise, 31*(3), 437.

Baechle, T. R., & Earle, R. W. (2008). Essentials of Strength and Conditioning (T. R. Baechle & R. W. Earle Eds. 3rd ed.): Human Kinetics.

Baker, D., & Nance, S. (1999). The relation between running speed and measures of strength and power in professional rugby league players. *Journal of Strength and Conditioning Research, 13*(3), 230-235.

Ball, N., & Zanetti, S. (2012). Relationship between reactive strength variables in horizontal and vertical drop jumps. *Journal of Strength and Conditioning Research*, *26*(5), 1407-1412.

Barnes, L. J., Schilling, K. B., Falvo, J. M., Weiss, W. L., Creasy, K. A., & Fry, C. A. (2007). Relationship of jumping and agility performance in female volleyball athletes. *Journal of Strength and Conditioning Research*, *21*(4), 1192-1196.

Barr, M., & Nolte, V. (2011). Which Measure of Drop Jump Performance Best Predicts Sprinting Speed? *Journal of Strength and Cond. Research*, *25*(7), 1976-1982.

Barr, M., & Nolte, V. (2014). The importance of maximal leg strength for female athletes when performing drop jumps. *Journal of Strength and Conditioning Research*, *28*(2), 373-380.

Bassa, E. I., Patikas, D., Panagiotidou, A. I., Papadopoulou, S. D., Pylianidis, T. C., & Kotzamanidis, C. M. (2012). The effect of dropping height on jumping performance in trained and untrained prepubertal boys and girls. *Journal of Strength and Conditioning Research*, *26*(8), 2258-2264.

Bissas, A. I., & Havenetidis, K. (2008). The use of various strength-power tests as predictors of sprint running performance. *Journal of Sports Medicine and Physical Fitness*, 48(1), 49.

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

Bobbert, M. F., Huijing, P. A., & van Ingen Schenau, G. J. (1987). Drop jumping. The influence of jumping technique on the biomechanics of jumping. *Medicine & Science in Sports & Exercise 19*, 332-338.

Bobbert, M. F., Mackay, M., Schinkelshoek, D., Huijing, P. A., & van Ingen Schenau, G. J. (1986). Biomechanical analysis of drop and countermovement jumps. *European Journal of Applied Physiology and Occupational Physiology*, *54*, 566-573.

Bojsen-Moller, J., Magnusson, S., Kjaer, M., & Aagaard, P. (2005). Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures. *Journal of Applied Physiology, 99*(3), 986-994.

Bosco, C., Viitasalo, J. T., Komi, P. V., & Luhtanen, P. (1982). Combined effect of elastic energy and myoelectrical potentiation during stretch-shortening cycle exercise. *Acta Physiologica Scandinavica, 114*(4), 557-565.

Bret, C., Rahmani, A., Dufour, A. B., Messonnier, L., & Lacour, J. R. (2002). Leg strength and stiffness as ability factors in 100 m sprint running. *The Journal of Sports Medicine and Physical Fitness, 42*(3), 274.

Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport: a review of resistance training studies. *Sports Medicine, 38*(12), 1045.

Byrne, P., Kenny, J., & Rourke, B. (2014). Acute Potentiating Effect of Depth Jumps on Sprint Performance. *Journal of Strength and Conditioning Research, 28*(3), 610-615.

Byrne, P., Moran, K., Rankin, P., & Kinsella, S. (2010). A comparison of methods used to identify optimal drop height for early phase adaptations in depth jump training. *Journal of Strength and Conditioning Research, 24*(8), 2050-2055.

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

Cavagna, G. A., Citterio, G., & Jacini, P. (1975). Proceedings: The additional mechanical energy delivered by the contractile component of the previously stretched muscle. *The Journal of Physiology*, *251*(1), 65P-66P.

Chen, Z.-R., Wang, Y.-H., Peng, H.-T., Yu, C.-F., & Wang, M.-H. (2013). The acute effect of drop jump protocols with different volumes and recovery time on countermovement jump performance. *Journal of Strength and Conditioning Research, 27*(1), 154-158.

Chiang, C., McInnis, T., & Sato, K. (2012). Using a vertical jump as monitoring purpose of resistance training progress for women's volleyball. *Medicine and Science In Sports and Exercise, 44*, 575-575.

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power: part 1--biological basis of maximal power production. *Sports Medicine, 41*(1), 17.

Crewther, B., Cronin, J., & Keogh, J. (2006). Possible stimuli for strength and power adaptation - acute metabolic responses *Sports Medicine* (Vol. 36, pp. 65-78).

Csapo, R., Alegre, L. M., & Baron, R. (2011). Time kinetics of acute changes in muscle architecture in response to resistance exercise. *Journal of Science and Medicine in Sport, 14*(3), 270-274.

Earp, E. J., Kraemer, J. W., Newton, U. R., Comstock, A. B., Fragala, S. M., Dunn-Lewis, R. C., . . . Maresh, M. C. (2010). Lower-body muscle structure and its role in jump performance during squat, countermovement, and depth drop jumps. *Journal of Strength and Conditioning Research, 24*(3), 722-729.

Earp, J., Kraemer, W., Cormie, P., Volek, J., Maresh, C. M., Joseph, M., & Newton, R. U. (2011). Influence of muscle- tendon unit structure on rate of force development during the squat, countermovement, and drop jumps. *Journal of Strength and Conditioning Research, 25*(2), 340-347.

Ebben, W. P., Fauth, M., Kaufmann, C. E., & Petushek, E. (2010). magnitude and rate of mechanical loading of a variety of exercise modes. *Journal of Strength and Conditioning Research, 24*(1), 213-217.

Edman, K. A., Elzinga, G., & Noble, M. I. (1978). Enhancement of mechanical performance by stretch during tetanic contractions of vertebrate skeletal muscle fibres. *The Journal of Physiology, 281*, 139.

Feldmann, C., Weiss, L., Ferreira, L., Schilling, B., & Hammond, K. (2011). Reactive strength index and ground contact time: reliability, precision, and association with drop vertical jump displacement. *Journal of Strength and Conditioning Research, 25*, S1.

Feldmann, R. C., Weiss, W. L., Schilling, K. B., & Whitehead, N. P. (2012b). Association of drop vertical jump displacement with select performance variables. *Journal of Strength and Conditioning Research, 26*(5), 1215-1225.

Flanagan, E., Ebben, W. P., & Jensen, R. (2008). Reliability of the reactive strength index and time to stabilization during depth jumps. *Journal of Strength and Conditioning Research*, *22*(5), 1677-1682.

Garhammer, J. (1993). A Review of power output studies of olympic and powerlifting: methodology, performance prediction, and evaluation tests. *Journal of Strength & Conditioning Research*, *7*(2), 76-89.

Gathercole, J. R., Sporer, C. B., Stellingwerff, G. T., & Sleivert, G. G. (2015). comparison of the capacity of different jump and sprint field tests to detect neuromuscular fatigue. *Journal of Strength and Conditioning Research, 29*(9), 2522-2531.

Güllich, A., & Schmidtbleicher, D. (1996). MVC-induced short-term potentiation of explosive force. *New Studies in Athletics*, 11, 67-84.

Gollhofer, A., Strojnik, V., Rapp, W., & Schweizer, L. (1992). Behaviour of triceps surae muscle-tendon complex in different jump conditions. *European Journal of Applied Physiology and Occupational Physiology, 64*(4), 283-291.

Gulick, D. T., Fagnani, J., Long, M., Morris, K., Hartzell, B., & Epler, M. (2008). Parameters that influence vertical jump height. *The Sport Journal*, *11*(3).

Hansen, K., Cronin, J., Pickering, S., & Douglas, L. (2011). Do force-time and power-time measures in a loaded jump squat differentiate between speed performance and playing level in elite and elite junior rugby union players? *Journal of Strength and Conditioning Research, 25*(9), 2382-2391.

Henry, F. M., & Whitley, J. D. (1960). Relationships between individual differences in strength, speed, and mass in an arm movement. *Research Quarterly*. *American Association for Health, Physical Education and Recreation*, 31(1), 24-33.

Hornsby, W. G., III. (2013). *A Systematic Approach to the Monitoring of Competitive Weightlifters.* Thesis (Ph.D.). East Tennessee State University, 2013., Johnson City, Tennessee.

Hudgins, T. B., Scharfenberg, M. J., Triplett, M. N., & McBride, M. J. (2013). Relationship between jumping ability and running performance in events of varying distance. *Journal of Strength and Conditioning Research, 27*(3), 563-567.

Hunter, R. G., McCarthy, P. J., Carter, J. S., Bamman, M. M., Gaddy, S. E., Fisher, P. G., . . . Newcomer, R. B. (2015). Muscle fiber type, achilles tendon length, potentiation, and running economy. *Journal of Strength and Conditioning Research*, *29*(5), 1302-1309.

Ikegawa, S., Funato, K., Tsunoda, N., Kanehisa, H., Fukunaga, T., & Kawakami, Y. (2008). Muscle force per cross-sectional area is inversely related with pennation angle in strength trained athletes. *Journal of Strength and Conditioning Research, 22*(1), 128-131.

Israetel, M. A. (2013). *The Interrelationships of Fitness Characteristics in Division 1 Athletes.* Thesis (Ph.D.). East Tennessee State University, 2013., Johnson City, Tennessee

Jensen, L. R., & Ebben, P. W. (2007). Quantifying plyometric intensity via rate of force development, knee joint, and ground reaction forces. *Journal of Strength and Conditioning Research, 21*(3), 763-767.

Kale, M., A_çi, A., Bayrak, C., & Açikada, C. (2009). Relationships among jumping performances and sprint parameters during maximum speed phase in sprinters. *Journal of Strength and Conditioning Research, 23*(8), 2272-2279.

Klavora, P. (2000). Vertical-jump tests: a critical review. *Strength and Conditioning Journal., 22*(5), 70.

Kollias, I., Panoutsakopoulos, V., & Papaiakovou, G. (2004). Comparing jumping ability among athletes of various sports: vertical drop jumping from 60 centimeters. *Journal of Strength and Conditioning Research, 18*(3), 546-550.

Kristianslund, E., & Krosshaug, T. (2013). Comparison of drop jumps and sport-specific sidestep cutting. *The American Journal of Sports Medicine, 41*(3), 684-688.

Kyröläinen, H., Avela, J., McBride, J., Koskinen, S., Andersen, J., Sipilä, S., . . . Komi, P. (2004). Effects of power training on mechanical efficiency in jumping. *European Journal of Applied Physiology, 91*(2-3), 155-159.

Leukel, C., Taube, W., Gruber, M., Hodapp, M., & Gollhofer, A. (2008). Influence of falling height on the excitability of the soleus H-reflex during drop-jumps. *Acta Physiologica, 192*(4), 569-576.

Lockie, G. R., Callaghan, J. S., Berry, P. S., Cooke, A. E. R., Jordan, A. C., Luczo, M. T., & Jeffriess, D. M. (2014). Relationship between unilateral jumping ability and asymmetry on multidirectional speed in team- sport athletes. *Journal of Strength and Conditioning Research*, *28*(12), 3557-3566.

Marshall, B., & Moran, K. (2013). Which drop jump technique is most effective at enhancing countermovement jump ability, “countermovement” drop jump or “bounce” drop jump? *Journal of Sports Sciences*, 1-7.

Matic, S. M., Pazin, R. N., Mrdakovic, D. V., Jankovic, N. N., Ilic, B. D., & Stefanovic, L. J. D. (2015). Optimum drop height for maximizing power output in drop jump: the effect of maximal muscle strength. *Journal of Strength and Conditioning Research*, *29*(12), 3300-3310.

McBride, J. M., & Snyder, J. G. (2012). Mechanical efficiency and force–time curve variation during repetitive jumping in trained and untrained jumpers. *European Journal of Applied Physiology*, *112*(10), 3469.

McBride, J.M, Triplett-McBride, T., Davie, Allan, Newton, R.U.. (1999). A Comparison of strength and power characteristics between power lifters, olympic lifters, and sprinters. *Journal of Strength and Conditioning Research*, *13*(1), 58.

McBride, M. J., McCaulley, O. G., & Cormie, O. P. (2008). Influence of preactivity and eccentric muscle activity on concentric performance during vertical jumping. *Journal of Strength and Conditioning Research*, *22*(3), 750-757.

Mirkov, D. M., Nedeljkovic, A., Milanovic, S., & Jaric, S. (2004). Muscle strength testing: evaluation of tests of explosive force production. *European Journal of Applied Physiology*, *91*(2-3), 147-154.

Moir, G., Button, C., Glaister, M., & Stone, M. H. (2004). Influence of familiarization on the reliability of vertical jump and acceleration sprinting performance in physically active men. *Journal of Strength and Conditioning Research, 18*(2), 276-280.

Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *Journal of Strength and Conditioning Research, 22*(3), 699-707.

Paavolainen, L., Hakkinen, K., Hamalainen, I., Nummela, A., & Rusko, H. (2003). Explosive-strength training improves 5-km running time by improving running economy and muscle power. *Scandinavian Journal of Medicine & Science in Sports, 13*(4), 272-272.

Perrine, J. J., Gregor, R., Munroe, R., & Edgerton, V. R. (1978, January). Muscle power capacities and temporal output patterns of skilled vs non-skilled vertical jumpers. *Medicine and Science in Sports and Exercise*. Vol. 10, No. 1, pp. 64-64.

Perttunen, J., Kyrolainen, H., Komi, P. V., & Heinonen, A. (2000). Biomechanical loading in the triple jump. *Journal of Sports Sciences, 18*(5), 363-370.

Peterson, D. M., Alvar, A. B., & Rhea, R. 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.

Robbins, W. D., & Young, B. W. (2012). Positional relationships between various sprint and jump abilities in elite american football players. *Journal of Strength and Conditioning Research, 26*(2), 388-397.

Sams, M. L. (2014). *Comparison of Static and Countermovement Jump Variables in Relation to Estimated Training Load and Subjective Measures of Fatigue.* Thesis (M.A.). East Tennessee State University, 2014. Johnson City, Tennessee.

Sands, W., Stone, M., McNeal, Jr., Jemni, M., & Haff, G. (2006). Estimation of power output from static and countermovement vertical jumps: junior national team male gymnasts. *Medicine and Science In Sports and Exercise, 38*(5), S231-S232.

Schmidtbleicher , D. (1992). Training for power events. *Strength and Power in Sport.* Oxford, UK.

Secomb, J. L., Lundgren, L. E., Farley, O. R., Tran, T. T., Nimphius, S., & Sheppard, J. M. (2015). Relationships between lower-body muscle structure and lower-body strength, power, and muscle-tendon complex stiffness. *Journal of Strength & Conditioning Research*, 29(8), 2221-2228.

Sheppard, J. M., Nolan, E., & Newton, R. U. (2012). Changes in strength and power qualities over two years in volleyball players transitioning from junior to senior national team.(Author abstract)(Report). *Journal of Strength and Conditioning Research*, *26*(1), 152.

Siff, M. C. (2003). *Supertraining* (5th ed.). Supertraining Institute.

Stone, M., O'Bryant, H., McCoy, L., Coglianese, R., Lehmkuhl, M., & Shilling, B. (2003). Power and maximum strength relationships during performance of dynamic and static weighted jumps. *Journal of Strength and Conditioning Research*, 17(1).

Stone, M. H., Stone, M., & Sands, W. A. (2007). *Principles and Practice of Resistance Training.* Champaign, IL: Human Kinetics.

Sukop, J., & Nelson, R. C. (1974). Effects of isometric training on the force-time characteristics of muscle contractions. *Biomechanics, IV*, 440-447.

Taube, W., Leukel, C., Lauber, B., & Gollhofer, A. (2012). The drop height determines neuromuscular adaptations and changes in jump performance in stretch-shortening cycle training. *Scandinavian Journal of Medicine and Science in Sports.* (5), 671.

Taylor, K., Chapman, D., Cronin, J., Newton, M., & Gill, N. (2012). Fatigue monitoring in high performance sport: a survey of current trends. *Journal of Australian Strength and Conditioning, 20*(1), 12-23.

Terzis, G., Georgiadis, G., Vassiliadou, E., & Manta, P. (2003). Relationship between shot put performance and triceps brachii fiber type composition and power production. *European Journal of Applied Physiology, 90*(1-2), 10.

Terzis, G., Spengos, K., Karampatsos, G., Manta, P., & Georgiadis, G. (2009). Acute Effect of Drop Jumping on Throwing Performance. *Journal of Strength and Conditioning Research, 23*(9), 2592-2597.

Thomas, T. R., Zebas, C. J., Bahrke, M. S., Araujo, J., & Etheridge, G. L. (1983). Physiological and psychological correlates of success in track and field athletes. *British Journal of Sports Medicine, 17*(2), 102.

Thorstensson, A., Karlsson, J., Viitasalo, J. H. T., Luhtanen, P., & Komi, P. V. (1976). Effect of strength training on emg of human skeletal muscle. *Acta Physiologica Scandinavica, 98*(2), 232-236.

Verkhoshansky, Yuri (1966). Perspectives in the Improvement of Speed Strength Preparation of Jumpers. *Legkaya Atletika (Track and Field),* 9.

Verkhoshansky, Y. V. (1996). Quickness and velocity in sports movements. *New Studies in Athletics,* 11, 29-38.

Verkhoshansky, Y., & Verkhoshansky, N. (2011). *Special Strength Training; Manual for Coaches*. Rome, Italy: Verkhoshansky SSTM.

Viitasalo, J., Salo, A., & Lahtinen, J. (1998). Neuromuscular functioning of athletes and non-athletes in the drop jump. *European Journal of Applied Physiology and Occupational Physiology 78*(5), 432-440.

Wallace, J. B., Kernozek, W. T., White, M. J., Kline, E. D., Wright, A. G., Peng, A. H.-T., & Huang, A. C.-F. (2010). Quantification of vertical ground reaction forces of popular bilateral plyometric exercises. *Journal of Strength and Conditioning Research, 24*(1), 207-212.

Walsh, M., Arampatzis, A., Schade, F., & Bruggemann, G. P. (2004). The effect of drop jump starting height and contact time on power, work performed, and moment of force. *Journal of Strength and Conditioning Research, 18*(3), 561-566.

Wilson, J. M., Loenneke, J. P., Jo, E., Wilson, G. J., Zourdos, M. C., & Kim, J.-S. (2012). The effects of endurance, strength, and power training on muscle fiber type shifting. *Journal of Strength and Conditioning Research, 26*(6), 1724.

Young, W., McLean, B., & Ardagna, J. (1995). Relationship between strength qualities and sprinting performance. *The Journal of Sports Medicine and Physical Fitness 35*(1), 13-19.

Zatsiorsky, V. M., & Kraemer, W. J. (1995). *Science and Practice of Strength Training*. Champaign, IL: Human Kinetics.

Ziv, G., & Lidor, R. (2010). Vertical jump in female and male volleyball players: a review of observational and experimental studies. *Scandinavian journal of medicine & science in sports*. 20.4: 2010, pp. 556-567.

APPENDICES

Appendix A: Informed Consent Documents

PRINCIPAL INVESTIGATOR: Cameron Griggs

TITLE OF PROJECT: Relationship between maximal lower body strength, countermovement jump, and optimal drop jump drop height

This Informed Consent contains important information related to your participation in this research study. Please read this material carefully and then decide if you wish to be a volunteer.

PURPOSE

The purpose(s) of this research study is/are as follows:

1) Determine relationship between lower body strength as measured by one repetition maximum back squat and optimal drop jump drop height (defined as the drop height from a box that results in the highest jump height).
2) Determine relationship between maximal countermovement jump height and optimal drop jump drop height (defined as the drop height from a box that results in the highest jump height).
The results from this study will be used by sport science practitioners in the future for prescribing drop jump drop heights for the purposes of maximizing jump height in training, exercise testing, or monitoring.
This study does not involve an investigational and/or marketed drug or device.

DURATION

This study includes three sessions. Each session should take no more than 90 minutes. The sessions will be separated by 48 to 96 hours to allow for recovery. The entire duration of this study will not exceed 12 days before completion.

PROCEDURES

The procedures, which will involve you as a research subject, include:

During session one you will answer questions regarding your age, training experience, estimated one repetition maximum back squat, and injury history. You will also be measured for height, femur length, tibia length, fibula length, foot length, and body mass. You will perform back squats with a 20 kilogram barbell for observation by the primary investigator. After squatting you will be asked to perform submaximal unweighted countermovement jumps and drop jumps. Drop jumps will be done from varying heights between 30 cm and 50 cm. If you are unable to safely perform back squats, countermovement jumps, or drop jumps you will be excluded from this study. During session two you will perform a one repetition maximum back squat for data collection. During session three you will perform maximal countermovement jumps and maximal drop jumps for data collection. No invasive techniques will be used during this study. Participants are asked to refrain from strenuous physical activity 48 hours prior to all sessions.

APPROVED
By the ETSU IRB
JAN 14 2016
By: Chair IRB Coordinator

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Date: / / version date: 1/12/16 Page 1 of 4 Subject Initials _____

PRINCIPAL INVESTIGATOR: Cameron Griggs

TITLE OF PROJECT: Relationship between maximal lower body strength, countermovement jump, and optimal drop jump drop height

ALTERNATIVE PROCEDURES/TREATMENTS

The alternative procedures/treatments available to you if you elect not to participate in this study are:

There are no alternative procedures/treatments available to you if you elect not to participate in this study.

POSSIBLE RISKS/DISCOMFORTS

The possible risks and/or discomforts of your involvement include:

Muscle strains, bone fractures, connective tissue sprains, and soreness post-exercise are possible risks. Risks encountered during this study will not exceed those normally experienced during high intensity exercise or testing. If you should become injured or you suspect an injury has occurred you must notify the primary investigator immediately.

POSSIBLE BENEFITS

The possible benefits of your participation are:

Participants will have one repetition maximum back squat, countermovement jump height, and optimal drop jump drop height measured by qualified sport scientists. These results can be used by participants to determine future training goals or when prescribing training intensities. Sport science practitioners will benefit from this study by using the results to optimize training, testing, or monitoring for their athletes.

COMPENSATION FOR MEDICAL TREATMENT:

East Tennessee State University (ETSU) will pay the cost of emergency first aid for any injury that may happen as a result of your being in this study. ETSU makes no commitment to pay for any other medical treatment. Claims against ETSU or any of its agents or employees may be submitted to the Tennessee Claims Commission. These claims will be settled to the extent allowable as provided under TCA Section 9-8-307. For more information about claims call the Chairman of the Institutional Review Board of ETSU at 423/439-6055.

APPROVED
By the ETSU IRB
JAN 14 2016
By: Chair IRB Coordinator

DOCUMENT VERSION EXPIRES
NOV 04 2016
ETSU IRB

PRINCIPAL INVESTIGATOR: Cameron Griggs

TITLE OF PROJECT: Relationship between maximal lower body strength, countermovement jump, and optimal drop jump drop height

FINANCIAL COSTS

The possible financial costs to you as a participant in this research study are:

There are no additional costs to participants that may result from participation in this study.

VOLUNTARY PARTICIPATION

Participation in this research experiment is voluntary. You have at least 24 hours to decide whether you participate. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. Refusing to participate or withdrawing will not impact your grades if you are enrolled in a sports science class. You may quit by calling Cameron Griggs, whose phone number is (803) 429-9094. You will be told immediately if any of the results of the study should reasonably be expected to make you change your mind about staying in the study.

CONTACT FOR QUESTIONS

If you have any questions, problems or research-related medical problems at any time, you may call Cameron Griggs at (803) 429-9094, or James Miller at (865) 603-5140. You may call the Chairman of the Institutional Review Board at 423/439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423/439-6055 or 423/439/6002.

CONFIDENTIALITY

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in the office of the Olympic Training Site at ETSU, room E113, for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, ETSU, and personnel particular to this research (department of kinesiology and sport science) have access to the study records. If you are a member of a club or sports team your testing results will be available to your coach. Your records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

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PRINCIPAL INVESTIGATOR: Cameron Griggs

TITLE OF PROJECT: Relationship between maximal lower body strength, countermovement jump, and optimal drop jump drop height

By signing below, you confirm that you are at least 18 years of age and have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project.

SIGNATURE OF PARTICIPANT	DATE
PRINTED NAME OF PARTICIPANT	DATE
SIGNATURE OF INVESTIGATOR	DATE
SIGNATURE OF WITNESS (if applicable)	DATE

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Appendix B: Data Collection Documents

Session one: Familiarization

Participant: Date:

Age (yrs): Birth date:

Body mass (kg): trial 1_____ trial 2_____

Height (cm): trial 1_____ trial 2_____

Injury history (6 mo.):

Years of back squat training experience:

Years of CMJ training experience:

Years of drop jump training experience:

Estimated one repetition maximum back squat (kg):

General warm-up:

1. Cycle ergometer set @ 50 W – pedal @ 70 rpm for 2 minutes _____

Dynamic warm-up:

1. 25 jumping jacks _____
2. 10 bodyweight squats _____
3. 10 walking lunges _____
4. 10 side lunges _____
5. 10 good mornings _____

Back Squats with 20 kilogram bar (2 sets of 5 repetitions): _____ _____
Safety pin set at: _____

CMJ: 50% effort _____ 75% effort _____

DJ (two trials min.): 30 cm _____ 40 cm _____ 50 cm _____

Notes:____

Session two: Back Squat data collection

Participant: Date:

Estimated 1RM back squat: _____ safety pin:

General warm-up:

Cycle ergometer set @ 50 W – pedal @ 70 rpm for 2 minutes _____

Dynamic warm-up:

25 jumping jacks _____

10 bodyweight squats _____

10 walking lunges (5 each leg) _____

10 side lunges (5 each leg)_____

10 good mornings _____

Specific warm-up:

1. 7 reps with 20 kg bar _____ ( )
2. 5 reps @ 50% _____ ( )
3. 3 reps @ 70% _____ ( )
4. 2 reps @ 80% _____ ( )
5. 1 rep @ 90% _____ ( )
6. 1 rep @ 95% _____ ( )

1RM attempts		Successful?
1		
2		
3		
4		
5		

1RM back squat _____

Session three: CMJ and DJ data collection

Participant: Date:

General warm-up:

Cycle ergometer set @ 50 W – pedal @ 70 rpm for 2 minutes _____

Dynamic warm-up:

25 jumping jacks _____

10 bodyweight squats _____

10 walking lunges (5 each leg) _____

10 side lunges (5 each leg)_____

10 good mornings _____

CMJ:

Submaximal jump @ 50% _____ 75% _____

100% CMJ	Trial 1	Trial 2	Trial 3	Trial 4
JH (cm)				

DJ: Submaximal jump 30 cm @ 50% _____ 75% _____

DJ drop height	Trial 1 (JH-cm)	Trial 2 (JH-cm)	Trial 3 (JH-cm)	Trial 4 (JH-cm)	Avg. (two highest)
30 cm					
40 cm					

Appendix C: List of Tables and Figures

Table 3.1 Participant descriptive data (N=15)

Descriptive measure	Mean ± SD
Age (yrs)	25.4 ± 2.8
Height (cm)	175.7 ± 6.1
Body mass (kg)	85.3 ± 14.7
Years BS	7.6 ± 4.7
Years CMJ	4.7 ± 5.1
Years DJ	1.8 ± 3

Note: BS = back squat; CMJ = countermovement jump; DJ = drop jump.

Table 3.2. General/Dynamic warm-up

7. Cycle ergometer set at 50 W – 70 rpm for 2 minutes
8. 25 jumping jacks
9. 10 bodyweight squats
10. 10 walking lunges
11. 10 side lunges
12. 10 goodmornings

Table 3.3 Summary of testing results (N=15)

Performance measure	Mean ± SD
Optimal drop height (cm)	55.7 ± 18.0
Relative 1RM back squat	1.9 ± 0.38
CMJ height (cm)	37.2 ± 5.9

Table 3.4 Correlations among performance measures (N=15)

	DHopt	1RMrel	CMJH
DHopt	1.00		
1RMrel	.214	1.00	
CMJH	.464	.620	1.00

Note: DHopt = optimal drop height; 1RMrel = relative one-repetition maximum back squat; CMJH = countermovement jump height

Table 3.5 Summary of testing results without Powerlifters (N = 13)

Performance measure	Mean ± SD
Optimal drop height (cm)	57.9 ± 18.1
Relative 1RM back squat	1.81 ± .28
CMJ height (cm)	36.5 ± 6.0

Table 3.6 Correlations among performance measures (N=13)

	DHopt	1RMrel	CMJH
DHopt	1.00		
1RMrel	0.645	1.00	
CMJH	0.690	0.673	1.00

Note: DHopt = optimal drop height; 1RMrel = relative one-repetition maximum back squat; CMJH = countermovement jump height

Figure 2.1 Force-velocity and power curves. Adapted from Zatsiorsky (1995)

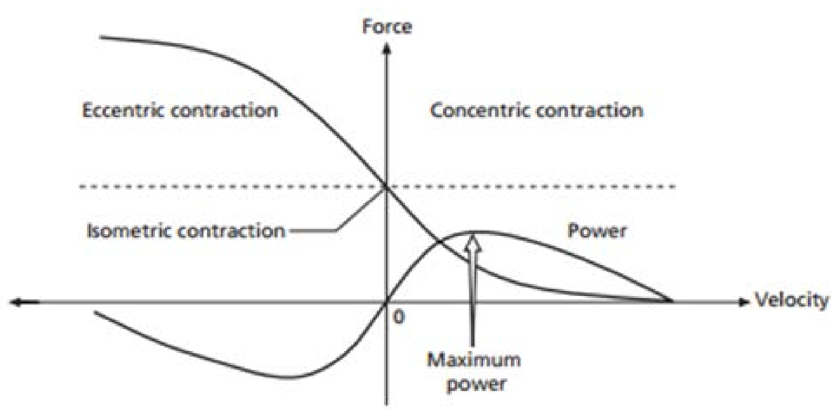


Fig. 2.2 Force-velocity curve for different types of jumps and sprinting. For the drop jump, force is no longer inversely proportional to the velocity of movement as is seen during the squat jump or dip (countermovement) jump. Adapted from Bosco (1982)

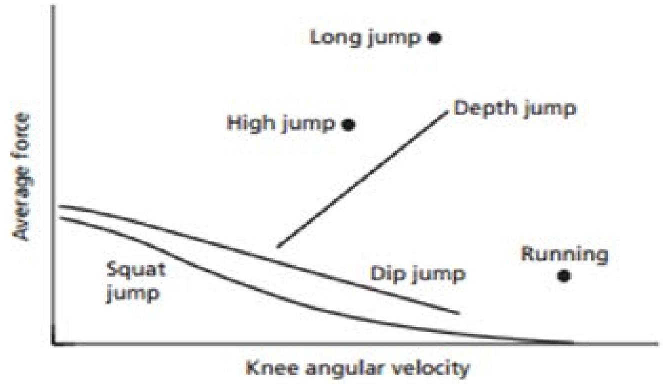


Figure 3.1 DJ testing set-up

Figure 3.2 Scatter plot with line of best fit for relative 1RM back squat (1RMrel) and optimal drop height (DHopt) results. Unfilled circles indicate cases suspected to be from a different population (i.e. Powerlifters) than the rest.

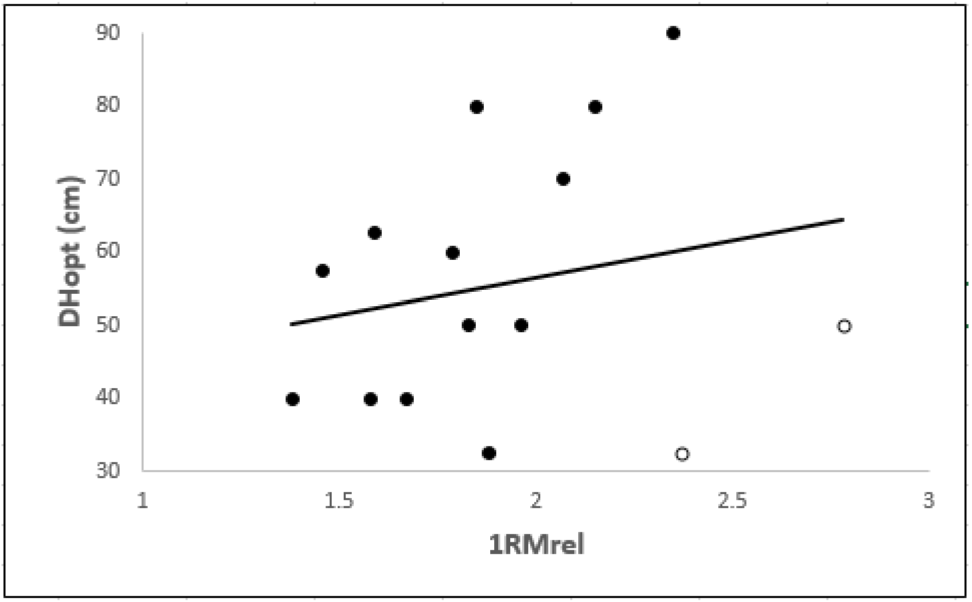
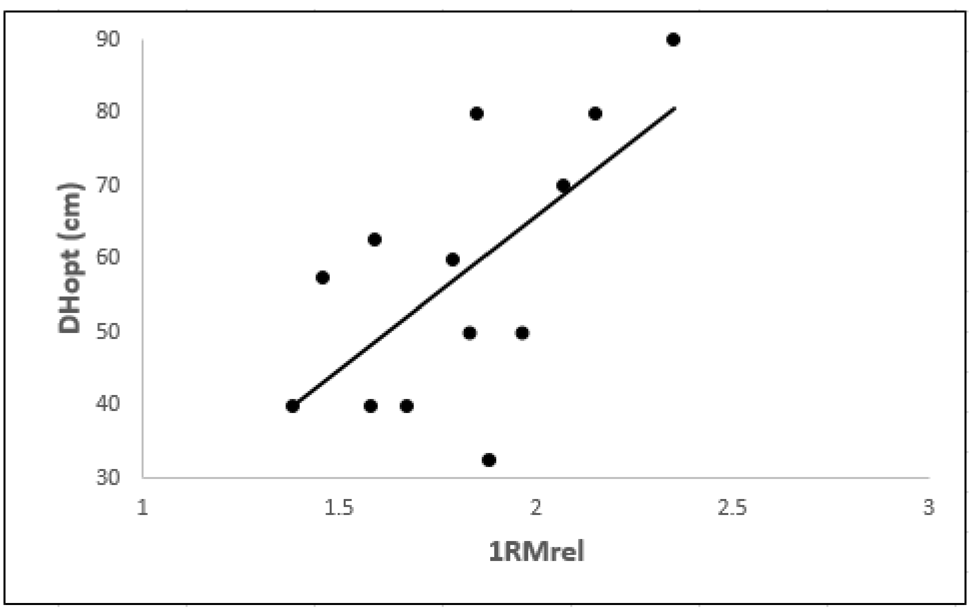


Figure 3.3 Scatter plot with line of best fit for relative 1RM back squat (1RMrel) and optimal drop height (DHopt) excluding outliers (i.e. Powerlifters) identified in Figure 3.2.



VITA

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Abbott H., Taber C., **Griggs C.**, Rhudy J., Keck S. (2015). *Power Output at Varying Loads During Squat Jumps.* Abstract presented at the 10th Annual Coaches and Sport Science College, Johnson City, Tennessee.