Comparison of the Hang High-Pull and Trap-Bar Jump Squat in the Development of Vertical Jump and Isometric Force-Time Characteristics

By

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Abstract

Olympic style weightlifting derivatives, such as the power clean and hang high-pull (HHP), are effective for improving a variety of explosive athletic performance measures. However, Olympic weightlifting movements have high skill demands and require expert coaching. Weighted jumps, such as the trap-bar jump squat (TBJS), have a comparably lower skill demand and may be equally effective for improving explosive performance. Yet, to date there is limited scientific research evaluating the effects of these movements and the transferability to high performance sport. **Purpose:** The purpose of the study was to compare vertical jump performance and isometric force and rate of force development (RFD) following a ten-week intervention employing either the HHP or TBJS in collegiate swimmers. **Methods:** Eighteen NCAA Division II swimmers (Male n=8; Female n=10), with at least one year of resistance training experience, volunteered for the study. The participants had a mean age, height, body weight and body fat percentage of 20.8 ± 3.2 years, 172.6 ± 8.8 cm, 68.19 ± 11.06 kg and 15.6 ± 6.2%, respectively. Baseline and post-training tests included the squat jump (SJ), countermovement jump (CMJ) and the isometric mid-thigh pull (IMTP) performed on force plates (Pasco-Scientific) sampling at 500Hz. The SJ and CMJ ground reaction forces (Fz) were analysed using a custom built software to obtain relative peak power (W/kg), and the impulse-momentum method was used to calculate takeoff velocity (m/s) and jump height (cm). The peak isometric force relative to body mass (N/kg), peak RFD (N/s) and relative force at five time bands was obtained from the IMTP Fz. Subjects were randomly assigned to a HHP training group or TBJS training group and completed a ten-week volume and intensity equated periodized strength and power training program. Loads and volumes for the HHP and TBJS were determined using percentages of the subjects' one repetition maximum (1-RM) power clean or trap-bar deadlift and were progressed over the supervised training sessions by a certified strength and conditioning specialist. **Results:** Paired sample t-tests revealed that all measured dependent variables significantly ($p < 0.05$) increased from pre- to post-test regardless of the intervention type used. The mean increases were not significantly ($p > 0.05$) different between the HHP and TBJS, although medium effect sizes were recorded for both relative peak power and vertical jump height in the SJ. Jump height for all subjects in the SJ and CMJ showed increases of 3.4 and 2.9 cm, respectively, while relative isometric peak force and peak RFD for all subjects increased by 3.6 N/kg and 570.5 N/s, respectively, after the 10-week intervention. **Conclusions:** Weighted jumps may be equally effective as weightlifting derivatives in the development of vertical jump height and power, and isometric force and RFD. Future studies may wish to examine different populations and other performance measures such as agility, acceleration and sprint metrics. Additionally, this study only examines the HHP and TBJS, while many other variations of Olympic style weightlifting movements and weighted jumps exist. **Practical Applications:** The results show that weighted jumps may be equally effective as weightlifting derivatives for improving athletic performance measures. However, weighted jumps require significantly less skill to perform, which may make weighted jumps a better option in a large team setting where coaching complex movements may be difficult or where equipment limitations may exist.

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Chapter 1

Introduction

Strength training is believed to have originated in ancient Greco-Roman times around the second century (Gardiner, 1930). The first story of the training principle known as overload comes from the ancient legend of Milo of Croton. Milos's story includes many tales of his legendary strength as well as an excellent wrestling career. As the legend is told, Milo gained his physical strength by lifting a calf every day. Over time the calf grew into a cow, and thus grew larger and larger causing Milo to slowly become stronger in order to continue to hoist the animal (Gardiner, 1930). This story, regardless of its validity is likely the first known recording of progressive overload as a training modality. Since the legend of Milo, variations in intensity, frequency and specificity over the course of a training program have become a key in developing strength and conditioning programs (Issurin, 2010).

In the 1920s, Janos Hugo Bruno "Hans" Selye, an Australian-Canadian endocrinologist, developed the idea of the General Adaptation Syndrome (GAS), which describes how an organism adapts to a stressor/stimulus (Verkhoshansky & Siff, 2009). Selye separated stress into two categories, known as eustress and distress (Verkhoshansky & Siff, 2009). Eustress is considered beneficial stress, which allows one to grow, whereas distress causes damage, decay, disease and death (Verkhoshansky & Siff, 2009). Selye and his GAS model states that all animals go through three phases when exposed to a stimulus, which are alarm, resistance and exhaustion (Verkhoshansky & Siff, 2009). The alarm phase is essentially the body's initial reaction to a stimulus such as resistance training (Verkhoshansky & Siff, 2009). This is followed by the resistance phase where the body uses its reserve energy, also known as current adaptation reserves (CAR), to adapt to the stimulus in an effort to maintain overall homeostasis (Verkhoshansky & Siff, 2009). The third phase, exhaustion is thought to occur when there is not enough energy reserves to sufficiently recover and adapt from the initial stimulus, which causes a subsequent decrease in performance (Verkhoshansky & Siff, 2009). However, if given enough time and resources the body can rebound from the exhaustion phase and super-compensate to a point where adaptations such as hypertrophy, accelerated muscle protein synthesis, increased enzyme activity and neurological recovery becomes more significant than if the exhaustion phase never occurred (Verkhoshansky & Siff, 2009). This theory laid the foundation for subsequent descriptions of the adaptation process such as the specific adaptation to imposed demands (SAID) principle, which was popularized in 1945 by army physician Thomas L. DeLorme (Todd, Shurley & Todd, 2012). SAID suggests that positive adaptations will continue to occur as long as volume and intensity are appropriately manipulated (Verkhoshansky & Siff, 2009). This is due to a combination of both mechanical and neural adaptations (Mann, Thyfault, Ivey, & Sayers, 2010). In 1964, Leonid Matveyev, a Russian sport-scientist, designed the traditional periodization model (Matveyev, 1964). In this model, training volume has an inverse relationship with the average intensity (Matveyev, 1964). During a training cycle, volume starts out high and intensity is relatively low (Matveyev, 1964). As the training cycle advances, volume begins to lower and intensity rises until volume is quite low while intensity is very high (Matveyev, 1964). Although there are earlier examples of periodization, many coaches and sport-scientists consider Leonid Matveyev as the father of traditional periodization (Issurin, 2010).

In the 1970s and 1980s, Yuri Verkhoshansky, Vladimir Issurin and Mike Stone developed models of periodization differing from the traditional model. Verkhoshansky is credited with creating and popularizing the conjugated-sequencing model (Verkhoshansky & Verkhoshansky, 2011), Issurin is known to have been the first to use block periodization as we know it today (Issurin, 2010), while Stone is credited with the phase-potentiation style of periodization (Stone, Stone & Sands, 2007). In the conjugated-sequencing model, each training day focuses on a different physical variable (Stone et al., 2007). Examples of training variables and/or training days in the conjugated model include maximal strength, dynamic/speed training and hypertrophy (Stone et al., 2007). Issurin's block periodization separated the training of key physical properties (hypertrophy, endurance, maximal strength, power, etc.) into different training "blocks", which typically last between 1-6 weeks (Issurin, 2010). Therefore an athlete may focus primarily on hypertrophy for four weeks while training other qualities very sparingly before changing to another block, which then focuses on a different quality (Issurin, 2010). Stone later took Issurin's block periodization to a more advanced/detailed sequencing where each block is specifically set up to increase the adaptations of the following block (Stone et al., 2007). These three models differ from the traditional periodization model that Matveyev popularized, as they all focus on improving the fitness abilities of one or two qualities at once instead of attempting to improve everything in a linear fashion. These models are based on the idea of long-term lag in the training effect, which states that there is a lag time between the stressor being applied and adaptations taking place (Verkhoshansky & Verkhoshansky, 2011).

Adaptation is the adjustment of an organism to its environment (Zatsiorsky & Kraemer, 2006). There are five features of the strength training adaptation process: overload, accommodation, variation, specificity, and individualization (Zatsiorsky & Kraemer, 2006). In order to improve maximal strength there must be progressive overload of specific musculature (Zatsiorsky & Kraemer, 2006). This overload must be sufficient as well as varied in order to avoid accommodation to the training stimulus (Zatsiorsky & Kraemer, 2006). Finally, the strength training program needs to be catered to the individual's needs in order to maximize adaptation (Haff & Triplett, 2015).

Lower body power is a physical quality required to varying degrees within the world of athletics and sport (Nibali, Champman, Robergs & Drinkwater, 2013). Lower body power is key in a variety of sports. Some examples are swimmers who need to explode off the starting platform as well as make powerful turns at the end of each pool length (Beretic, Durovic, Okicic & Dopsaj, 2013; West, Owen, Cunningham, Cook & Kilduff, 2011), to a soccer player who needs to accelerate and change directions quickly (Garcia, Martinez, Hita, Martinez & Latorre, 2014), to a football lineman whose main goal is to prevent the opponent from pushing him backwards (Smith et al., 2014). In nearly every sport where lower body power is important there are several additional qualities that are also of great significance. These qualities include coordination, flexibility, skill level, and mental performance; however, with all other qualities being equal, the stronger and more explosive athlete will have the advantage (Bompa & Haff, 2009). Due to this fact, sport coaches, as well as strength and conditioning professionals/coaches are constantly experimenting with new methods to further develop lower body power. Although traditional methods of strength training have been shown to be effective, the use of high velocity resistance training such as the Olympic lifts (cleans, snatches, jerks) and their variations (high-pulls, hang clean, hang high-pull etc.), have been shown to be superior to relatively slow velocity strength training (Channell & Barfield, 2008). Although the Olympic lifts and their variations are considered an effective means of improving lower body power (Haff et al., 2008; Hori et al., 2008), they can be difficult to teach and perform optimally (Fees & Martin, 1997). The high velocity movement of trap-bar jumps may be more effective and are known to be much easier to teach (Swinton, Stewart, Agouris, Keogh & Lloyd, 2011). Trap-bar deadlifts and jumps are also easier to track power development using force-plates and other devices when compared to the Olympic lifts and their variations (Kawamori, Rossi, Justice, Haff, Pistilli, O'Bryant & Haff, 2006). So far, no major studies focusing on trap-bar jumps or their effectiveness, using an intervention, have been published. Additionally, to this author's knowledge, only two studies has been published comparing the use of weightlifting derivatives to jump training (Teo, Newton, Newton, Dempsey & Fairchild, 2016; Tricoli, Lamas, Carnevale & Ugrinowitsch, 2005).

Purpose of the Study

The purpose of this study was to compare the development of lower body power, force and rate of force development (RFD) in NCAA Division II swimmers using either the hang high-pull (HHP) or the trap-bar jump-squat (TBJS) as their primary high velocity resistance training exercise. Specifically, this study tested whether or not the trap-bar squat-jump is a more efficient and effective means of improving lower body power, force and RFD when compared to the more common hang high-pull.

Statement of Research Question

Does the trap-bar jump-squat develop lower body force and explosive power in NCAA Division II swimmers more effectively than the barbell hang high-pull?

Hypotheses

The researcher hypothesized that neither the trap-bar jump squat (TBJS) nor the hang high-pull (HHP) will be significantly more effective than the other for improving outputs in the countermovement jump (CMJ), squat jump (SJ) or the Isometric Mid-Thigh Pull (IMTP). However, it was also hypothesised that the TBJS may do a slightly better job at improving the SJ and CMJ measurements, as the TBJS more closely mirrors a vertical jump compared to the HHP and other barbell movements. The researcher also hypothesised that the HHP may be slightly more effective at improving the IMTP measurements, since the IMTP and HHP are similar as they both involve exerting force on a barbell in front of the body at approximately mid-thigh height.

Significance of Study

The significance of the study was to attempt to demonstrate to the coaching and strength and conditioning community that the TBJS, as opposed to the HHP and by extension, other Olympic lifting variations, can be used as a viable means for improving lower body power in athletes. This could potentially change how many strength and conditioning coaches operate, as the Olympic lifts and their variations, such as the HHP, can be very difficult to teach, especially to large groups of athletes and may take a significant amount of time to develop proper and effective technique (Fees & Martin, 1997). The trap-bar squat-jump is relatively easy to teach and implement (Hori et al., 2008), is known to be safer (Swinton, Stewart, Lloyd, Agouris & Keogh, 2012), and could potentially be more effective than the HHP and other Olympic lift variations.

Delimitations

This study was delimited as follows:

1. Relatively low training age and pre-existing strength/power of the participants.
2. The study only included male and female swimmers, aged 18 to 23 years.
3. The study only included Division II athletes.
4. Relatively short intervention time of 10 weeks.
5. The study only examined the addition of either the HHP or TBJS.

Limitations

This study was limited as follows:

1. Differences in training experience and pre-existing strength/power of the participants.
2. Individual differences in lifestyle factors, such as sleep and stress, of the participants.
3. Changes in training outside of the weight-room.
4. Full compliance to training protocol.
5. Intake of food and supplements was not tracked/standardized outside of testing days.

Assumptions

1. Subjects matched their dietary and supplement intake on data collection days.
2. Data collection and data analysis equipment were calibrated and working properly.
3. Overall effort and motivation of participants was consistent during training and testing.
4. All subjects fully complied with the intervention over the entire 10 weeks.
5. Motivation remained constant throughout the intervention period.
6. Motivation was consistent from pre- and post-test.

Definition of Terms

Certified Strength & Conditioning Specialist (CSCS): Through the National Strength & Conditioning Association (NSCA). The most popular certification for strength & conditioning coaches in North America and many countries world-wide.

Countermovement Jump (CMJ): When an athlete, from a standing position drops into a semi-squat, immediately changes directions and jumps vertically (Waller, Gersick & Holman, 2013).

Core Lift: Multi-joint movements that involve one or more large muscle groups such as squat, bench press, pull-up and deadlift (Haff & Triplett, 2015).

Ground Reaction Forces (Fz): The forces, generally measured by force plates, which are exerted into the ground by an athlete. Typically measured during jumping movements.

Hang High-Pull (HHP): The athlete lifts a barbell from the ground to the standing position using a double over hand grip. The athlete then lowers the bar to around knee level by bending at the knees and hips before changing directions and accelerating the bar upwards to approximately sternum height.

High velocity resistance training: Training with loads that can be moved at a rapid rate of speed and acceleration (Verkhoshansky & Siff, 2009). This includes exercises such as jumps, sled-pulls, Olympic lifts, hang high-pull and trap-bar squat-jumps.

Impulse: The area under a specific part of the force-time curve. Typically used to calculate take-off velocity, vertical jump height and dynamic rate of force development. Typically expressed in Newton seconds (N.s) or kilogram meter per second (kg.m/s).

ISAK: International Society for the Advancement of Kinanthropometry.

Isometric Mid-Thigh pull (IMTP): Barbell is set under an immovable object (typically the spot catches of a power-rack) at the mid-thigh of the athlete. The athlete pulls as hard as they can attempting to lift the barbell.

Isometric Rate of Force Development (I-RFD): The rate of development of force under isometric conditions.

Kinanthropometry: Anatomical measurement of the human body as it relates to sport and movement.

Lower body power: The ability to produce significant force quickly from the waist down. Common tests for this quality would be sprints, long jump and vertical jumps.

NCAA: National Collegiate Athletics Association.

One repetition max (1-RM): The highest load that can be lifted with proper form for one maximal effort.

Overload: "The magnitude of a training stimulus that is above the habitual level" (Zatsiorsky & Kraemer, 2006).

Peak Power: The highest power output during a single movement.

Power Clean: Lifting the barbell, with a double over hand grip from the floor to the shoulders in one movement without squatting below parallel.

Rate of Force Development (RFD): The rate of rise in contractile force during muscle contraction. This is calculated from the force-time curve and can be analyzed at various times. RFD is expressed in Newtons per second (N/s) (Verkhoshansky & Siff, 2009).

Specificity: "The degree to which one movement is similar to another in kinetic, kinematic, and metabolic measures." (Stone et al., 2007).

Sport Coaches: The coach of an athletes' specific event/s.

Strength and Conditioning professional/coach: A coach whose primary goal is the physical development of athletes.

Squat Jump (SJ): When an athlete, from a standing position drops into a semi-squat, pauses for three seconds, before jumping vertically (Waller et al., 2013).

Traditional resistance training: The most common means for improving strength in athletes. The common exercises are squats, bench press, deadlifts, pull-ups and their variations.

Trap-bar: Also known as a Hex-bar. A training apparatus where the athlete stands inside a hexagonal shaped frame with two handles to the sides of the athlete. The trap-bar can be loaded with weights like a typical barbell.

Trap-Bar Jump Squat (TBJS): The athlete lifts the trap-bar from the floor to a standing position. The athlete lowers the bar by bending their knees and hips before changing directions and jumping with the trap-bar.

Weight-lifting Straps: Fabric bands that wrap around the athletes' wrists and a barbell or dumbbell to prevent loss of grip.

Chapter II

Review of Literature

Introduction

Lower body power is an important quality for many types of athletes in both individual and team sports (Verkhoshansky & Siff, 2009). Therefore, both sport coaches as well as strength and conditioning professionals are constantly looking for new ways to develop and maintain lower body power as effectively, efficiently and safely as possible. Traditional strength training such as squats and deadlifts (Channell & Barfield, 2008), as well as more explosive training methods such as Olympic lifts and jump squats are often employed (Hoffman, Ratamess, Lkatt, Faigenbaum, Ross, Tranchina & Kraemer, 2009). Although these training strategies have a long history of being effective, new methods are always being explored, including the trap-bar deadlifts and trap-bar jump squats (Swinton et al., 2011). Exercises utilizing the trap-bar may have an advantage over the older, more traditional exercises due to ease of use, biomechanical advantages, and the ability of being able to drop the bar safely at any time (Swinton et al., 2011).

Swimming

Swimming, although generally considered an upper-body dominant, endurance-based activity, does require lower body explosive power to be successful (Beretic et al., 2013; Bishop, Cree, Read, Chavda, Edwards & Turner, 2013; West, Owen, Cunningham et al., 2011). The first, and most obvious section of a race that requires explosive power is the start off of the blocks or from the wall in the pool (Beretic et al., 2013). This initial dive or start portion closely mimics the biomechanics of a jump (West, Owen, Cunningham et al., 2011). Explosive lower body power is also important at the end of each length of the pool as the swimmer must forcefully push off the wall to change direction and attempt to maintain or increase their speed throughout a race (Bishop et al., 2013). In a study by Bishop et al. (2013), it was determined that approximately 30% of a 50-meter race was taken up by the start (first 15 meters), followed by 15%, 7.5%, 4%, 2% and 1% of races of 100, 200, 400, 800 and 1500 meters, respectively. Therefore, it is apparent that the ability to have a good start, which is heavily based on explosive power, is key in the results of short distance swimmers (Beretic et al., 2013). In a study by Beretic and colleagues (2013), 23 national level, male Serbian swimmers (21.1 ± 4.3 yrs, 1.89 ± 0.10 m, 81.6 ± 8.4 kg) were tested for isometric peak RFD, isometric peak force and time to 50% of isometric peak force of their knee extensors using an iso-kinetic machine. The scores recorded on the iso-kinetic machine were analyzed and compared with each swimmer's first 10 meters from the start off the blocks (Beretic et al., 2013). It was found that peak force ($p = 0.002$) , peak RFD ($p < 0.001$) and time to 50% of peak force ($p = 0.04$) were all positively correlated to start performance, which led the researchers to conclude that lower body force and power production may be a key determinant in start performance, and therefore swim performance as a whole (Beretic et al., 2013).

Adaptations to Resistance Training

Besides the development of lower body power, many adaptations can arise from the use of resistance training. Of these adaptations, the ones with the greatest impact on athletic performance are those of improved neural recruitment patterns/rates, and an increase in the total cross-sectional area of the muscle tissue (Haff & Triplett, 2015). Increases in cross-sectional area, which have been found to relate very closely to the strength of a muscle (Powers & Howley, 2012), are influenced greatly by protein synthesis occurring at a higher rate than protein breakdown via a positive nitrogen balance (Powers & Howley, 2012). The other primary adaptation of neurological changes include an increase in motor-neuron firing frequency, increased rate coding, improved firing synchronicity, and an increase in the number of motor units that are being recruited (Haff & Triplett, 2015).

Hypertrophic Adaptations

One of the most important factors involved in athletic improvement is the development of muscle size, also known as muscular hypertrophy (Verkhoshansky & Siff, 2009). The increase in the size of the myofibrils in the muscle, also known as myofibril hypertrophy, is best achieved through resistance training (Verkhoshansky & Siff, 2009). This process occurs when protein synthesis occurs at a greater rate than protein breakdown, and results in an increase in size and thickness of actin and myosin within a muscle fiber (MacDougall, Sale, Moroz, Elder, Sutton & Howald, 1979). This increase in myofibril filament size results in a larger total cross-sectional area (CSA) of the muscle, which has been shown to have a very close relationship with maximal strength (Powers & Howley, 2012).

The physiological signalling processes involved with muscular hypertrophy are primarily stimulated by mechanical strain or stretch which causes muscular damage (Power & Howley, 2012). This mechanical strain occurs most notably during resistance training and results in an inflammatory response, which leads to a cascade of cytokine release and the proliferation and differentiation of satellite cells (Powers & Howley, 2012). Satellite cells then donate their nuclei to the surrounding muscle fibers, which increase the rate of protein synthesis (Powers & Howley, 2012). The mechanical damage also leads to an increased amount of insulin-like growth factor (IGF-1) and mechano-growth factor, which leads to increased muscle growth and reduced production and expression of inhibitory growth factors like myostatin (Verkhoshansky & Siff, 2009).

Muscle hypertrophy occurs to different degrees in the three muscle fiber types. These three fiber types include slow twitch fibers (Type I) and fast-twitch fibers (Type IIA and IIX). These fibers have different physical and functional properties and are genetically pre-determined; however training status can change the percentage of CSA that is made up by each fiber (Powers & Howley, 2012). As training shifts more towards endurance, there is a subsequent shift towards the more oxidative fibers as the Type IIA fibers change to take on more characteristics of Type I and Type IIX fibers take on characteristics of Type IIA fibers (Powers & Howley, 2012). This causes the muscle fibers to be able to contract for longer periods of time without fatiguing, but also results in a decreased potential for maximal power output (Stone et al., 2007). This shift of fiber types can occur both ways as training with high intensity and reduced volume results in a shift of the oxidative fibers to take on properties of the more glycolytic fast-twitch fibers (Kadi & Thornell, 1999). As shown by Ross & Leveritt (2001), the conversion of muscle fiber type can be reversed by differing degrees of de-training. This can be potentially useful as a properly timed taper may allow for a return of Type IIX fibers, allowing for greater power production (Ross & Leveritt, 2001). Unlike total growth of the muscle tissue, the conversion of muscle fiber types seems to occur quite quickly when a new stimulus or training cycle begins (Verkhoshansky & Siff, 2009). As little as eight weeks has been shown to result in a significant decrease in Type IIX and a matching increase in Type IIA concentration in resistance trained subjects (Staron et al., 1994). Although there is strong evidence that Type IIA fibers can take on many of the characteristics of Type I fibers, there is very little evidence to show that a full transition can occur like it has been shown between Type IIA and Type IIX (Haff & Triplett, 2015).

Additional means of muscle hypertrophy include changes in enzymatic activity from training. There has been very little evidence of significant enzyme changes from heavy resistance training, however high volume resistance and endurance training has been shown to create anaerobic and aerobic enzyme changes, respectively (Stone et al., 2007). Another side-effect of high volume resistance training is an increase in fatty acid oxidation post-exercise, which may lead to positive changes in body composition (McMillan, Stone, Satian, Marple, Keith et al., 1993). High volume resistance training, over time, has also been shown to enhance the acid-base balance in the tissues by increasing buffering capacity (Costil, Barnett, Sharp, Fink & Katz, 1983). This increase in lactic acid buffering allows the athlete to maintain force production and power output at a lower blood pH, which allows an athlete to train or compete at a high intensity for longer periods of time (Costill et al., 1983). Over time, high intensity resistance training can lead to an increase in adenosine triphosphate (ATP) and creatine phosphate (CP) stores within the muscle due to a super-compensation effect (MacDougall et al., 1979). Although not exactly an increase in the functional units of the muscles, an overall increase in muscle size can be accomplished by an increase in the storage of intramuscular glycogen content, which has been shown have an increased capacity after five months of heavy resistance training (MacDougall, Ward, Sale, & Sutton, 1977). This increase in intramuscular glycogen gives the athlete an increased amount of easily accessible fuel, which they can draw upon during high intensity activities (Powers & Howley, 2012).

Neuromuscular Adaptations

In addition to the hypertrophic adaptations that occur, resistance training is known to enhance neuromuscular function (Verkhoshansky & Siff, 2009). One of the most critical strategies for improving strength and power in an individual is the ability to increase neural drive (Verkhoshansky & Siff, 2009). This increased neural drive leads to the ability to recruit high threshold motor units (Type IIA and IIX) and starts in the primary motor cortex of the brain where an action potential begins (Verkhoshansky & Siff, 2009). This action potential continues down the spine, through the peripheral nervous system (PNS), until the action potential arrives and activates the specific muscle fibers that are needed to complete the task at hand (Powers & Howley, 2012). Through training, neural drive can be improved by increased rate coding, agonist and antagonist synchronization, and more synchronized timing of muscle contractions (Komi, 2003).

When an individual learns new motor patterns and/or when an individual is able to increase the amount of force that the muscles can produce, it is almost always, at least in part, due to an enhanced activation of the primary motor cortex (Dettmers, Lemon, Stephan, Fink, & Frackowiak, 1996). This is highlighted by research that has found that individuals who were untrained only activated approximately 71% of their muscle fibers compared to 86% in trained subjects when performing an isometric bicep curl (Adams, Harris, Woodard & Dudley, 1993). Resistance training can also improve the recruitment of high threshold motor units, which leads to improved force production capabilities (Komi, 2003). One of the governing principles in the order of motor unit activation is the "size-principle" which states that larger, typically stronger motor units have a higher activation threshold vs smaller, weaker motor units (Henneman, Wuerker & McPhedran, 1965). Additionally, smaller motor units are activated first and when they cannot complete the task at hand, larger motor units become activated (Powers & Howley, 2012). One of the benefits of consistent resistance training, is that the high threshold motor units begin to have a lower activation threshold (Komi, 2003). This means that the fast-twitch muscle fibers can be tapped into earlier and therefore rates of force development are increased (Komi, 2003).

Agonist muscles are the muscle groups that are responsible for the primary movement of a joint (Powers & Howley, 2012). The overall activation and synchronization of the agonist muscles is improved with resistance training by sending less neural signalling to the antagonistic and surrounding muscles (Felici et al., 2001; Milner-Brown, Stein, & Lee, 1975). When the motor units fire with improved synchronization, there is an increase in both force output as well as the speed in which that force is created in the muscles (Verkhoshansky & Siff, 2009). Although there is an increase in total force produced, Semmler and Nordstrong (1998) demonstrated that increased motor unit synchronization from resistance training had the most significant impact of the rate of force development.

The final primary neural adaptation seen from resistance training is the increase in rate coding in the muscle, which refers to the frequency of which motor units are activated (Verkhoshansky & Siff, 2009). When rate coding/activation frequency is increased, so too is the rate of force development (Komi, 2003). Resistance training is known to improve this activation of muscle fibers via the neurological system and therefore increase rate of force development (Komi, 2003). This was shown by Anderson and Aagaard (2006), who found that improving maximal strength, also increased rate coding, and thus the rate that force is developed.

Beyond the functional neural adaptations to resistance training, there are also structural changes that occur at the neuromuscular junction (Komi, 2003). Deschenes et al. (2000) found that after two months of resistance training, the motor end plates' surface area had significantly increased (Deschenes et al., 2000). This allowed for a greater release of the neurotransmitter acetylcholine, and therefore potentially faster production of the action potential needed for muscle contraction (Deschenes et al., 2000). Another adaptation is an enhanced stretch shortening cycle (SSC), also known as the stretch reflex (Bompa & Haff, 2009). The SSC is a very important and powerful means of increasing both total force production, as well as the rate of force development (Bompa & Haff, 2009). Enhancing the SSC is the result of several factors, which include enhanced elasticity of muscles and tendons as well as a reduced inhibition caused by the Golgi Tendon Organ (GTO) (Dietz & Peterson, 2012). This can be done via resistance training as the neural signals to the antagonist muscle groups are decreased, thus reducing the antagonist co-contraction (Carolan & Cafarelli, 1992). In addition, activating the GTO on a frequent basis via resistance and/or plyometric training can reduce the GTOs receptor sensitivity (Carolan & Cafarelli, 1992). As shown by Aagaard et al. (2000), having reduced GTO activity, reduces the inhibition of rapid and powerful muscle contractions, allowing for greater force production.

Strength Training Specificity

The degree to which training exercises have an effect on performance in competition is known as the "principle of specificity" or "transfer of training" (Stone et al., 2007). The more similar the training exercise is to the performance measure, the higher chance of having a positive effect there is (McDonagh & Davies, 1984). There are many factors that determine how specific/and transferable a training modality is to the performance measure. These include contraction velocity, contraction type, force production and movement pattern specificity (Kumar, Chaudhry, Reid & Boriek, 2002).

Movement Pattern Specificity

The degree to which a training exercise transfers to the primary movement is related to intermuscular movement pattern specificity (Stone et al., 2007). This means that training exercises that include similar joints, velocities, and positions have a greater degree of transfer to the primary movement. There is a large amount of research that has shown that the degree that strength improvements are strongly dependent on the similarity between the performance test and the exercises used (Channell & Barfield, 2008; Fry, Powell, & Kraemer, 1992; Harris, Stone, O'Bryant, Proulx & Johnson, 2000; Sale, 1988). Harris et al. (2000), conducted an investigation where subjects were split into several groups which included a high velocity group, a high force group and a combined high velocity and high force group (Harris et al., 2000). Each group focused on a specific type of training while all the other pieces of the training programs remained constant (Harris et al., 2000). One group trained with low loads with high velocity, one group trained with heavy weights and low velocities and the final group included a blend of these loads and velocities (Harris et al., 2000). At the end of the nine-week protocol the group who performed high velocity plyometric training, but not heavy back squats, improved in all performance measures except for the back squat, while the high force and combined groups, which both performed the back squat, increased their one repetition max (1-RM) in the back squat by 9.8% and 11.6%, respectively (Harris et al., 2000). The difference in back squat improvement between the mixed velocity/load group and the high load/low velocity group was not significant, which suggests that a mixed velocity program is likely better than a training program that utilized a low load, high velocity, or a high load, low velocity only approach (Harris et al., 2000). Wilson, Murphy and Walshe (1996), found a significant increase in 1-RM strength in the bench (12.4%) and squat (20.9%) after eight weeks of training bench and squat twice per week. However, this increase in 1-RM strength in the dynamic movements of the bench and squat transferred poorly to isokinetic contractions on a Bio-Dex (Wilson et al., 1996). This study highlights the importance of movement pattern specificity and specific joint angles in the transfer from training to performance (Wilson et al., 1996).

Additional studies have shown strong relationships between the Olympic lifts of the snatch and clean and jerk and the height reached in the vertical jump (VJ) as athletes with higher numbers in the olympic lifts commonly have the highest vertical jumps (Bompa & Haff, 2009, Channell & Barfield, 2008; Haff et al., 2005; West, Owen, Jones et al., 2011). This is due to the fact that both the Olympic lifts and the vertical jump include similar movement patterns (extension of the hips, knees and ankles), high power outputs, and require high rates of force development (RFD) (Bompa & Haff, 2009). Due to the concept of movement pattern specificity, one would likely conclude that performing weighted jumps would be more specific to improving vertical jump performance than that of the power clean, or its variations, due to the load being centered more over the center of mass of the athlete (Swinton et al., 2011; Turner, Tobin & Delahunt, 2015). MacKenzie, Lavers and Wallance (2014) found that, the countermovement and squat jumps are very similar biomechanically and although the power clean produced higher RFDs, the rates and order of extension of the knees, hips and ankles differ significantly from the jumping movements (Mackenzie et al., 2014). This is also demonstrated by research done by Swinton et al (2012), where they examined the peak force, peak velocities, jump heights and RFD during weighted jumps performed by professional rugby players. The athletes performed jumps with either a trap-bar or with a barbell on their backs (Swinton et al., 2012). The results showed that the athletes were able to produce more force and height at all resistance levels with the trap-bar over the barbell (Swinton et al., 2012).

Specificity of Contraction

The degree of transfer of the training exercise to the performance measure is affected not only by movement pattern specificity, but by contraction force, contraction velocity, and contraction type (Bompa & Haff, 2009). Harris et al. (2000) had 42 well trained football players (back squat ≥ 1.4 times body weight) train for nine weeks in either a high force (>80% 1-RM), speed-strength, (30-40% 1-RM) or combined training (speed-strength and high force) group. The researchers found that after the intervention, the high force and combination groups increased their maximal strength measures, however, the speed-strength group did not (Harris et al., 2000). Additionally, the combination group and speed-strength group improved on measures of power and explosiveness, whereas the high force group did not (Harris et al., 2000). A similar study using 43 volunteers looked at vertical jump, peak power, mean power, RFD and 1-RM squat after eight weeks of either plyometric, resistance or combined training (Fatourous, Jamurtas, Leontsini, Taxildaris, Kostpoulos & Buckenmeyer, 2000). As one would expect, results showed that the resistance training group improved in the 1-RM back squat more than the plyometric group, and the plyometric group improved their vertical jump by a greater degree when compared to the resistance training group (Fatourous et al., 2000). However, the combined training group had nearly the same gains in each performance measure while clearly outperforming the other groups in measures of force production (Fatourous et al., 2000). This study showed that contraction types play a critical role in the development of specific performance outcomes (Fatourous et al., 2000). Another take away from this study is that combining training types (high force, high velocity) can improve several qualities at once (Fatourous et al., 2000; Harris et al., 2000).

Another important concept to understand is being "strong enough" for the demands of the sport (Dietz & Peterson, 2012). In many sports, the athlete only needs to move themselves or an object; a great example of this is the throwing events in track and field (Dietz & Peterson, 2012). In the shot-put the male athlete must put the shot, which weighs 7.26 kg as far as possible (Dietz & Peterson. 2012). Shot-put athletes also often bench press over 180 kg which means they are moving roughly 90 kg with each arm (Dietz & Peterson, 2012). In this case, most of these athletes are strong enough to throw the shot extremely far, but one factor that separates throwers who win and those who do not is the ability to utilize their strength quickly by creating a rapid RFD (Dietz & Peterson, 2012). This highlights the fact that only improving maximal force output will not always allow an athlete to perform better in their sport (Verkhoshansky & Verkhoshansky, 2011).

Although there is a popular thought that super slow training (SST) involving both slow eccentric and concentric contractions, with the aim of increasing time under tension (TUT), may result in increased hypertrophy, the hypertrophy seen is not as great as the gains from heavy resistance training (Keeler, Finkelstein, Miller & Fernhall, 2001). While SST may have an application with rehabilitation and beginners due to relatively light loads, the total amount of muscular tension is typically too low to result in substantial strength and power gains over time (Stone et al., 2007). There is also some evidence, that in trained athletes, super slow training may actually lead to reduced maximal strength, power production and RFD (Stone et al., 2007).

As with movement pattern specificity, training specific types and speeds of muscle contraction can carry over to the performance measures. Isometric contractions at specific joint angles have been shown to be a good strategy to improve isometric strength at those joint angles, but does not translate very well to strength at different joint angles, or in the dynamic contraction types (Atha, 1981). Isometric contractions, due to the lack of mechanical stretch, are also not a substantial stimulus for muscle hypertrophy (Verkhoshansky & Siff, 2009). Exercises involving dynamic contractions are typically recommended for athletes as they work over a greater range of motion (ROM) and can transfer easily to other dynamic movements (Verkhoshansky & Siff, 2009). One sub-type of dynamic contraction is isokinetic training. This is where the angular velocity is maintained at a constant and is only really applicable via a machine such as a Bio-Dex. Although useful for rehabilitation and some types of strength testing, the specificity of movement pattern and velocity are not similar enough to real-world movement to result in significant performance improvements (Verkhoshansky & Siff, 2009). Much of this difference is due to the fact that muscular strength and thus speed of contraction changes as different joint angles that have different leverages and angles of pull on the joints involved (Bazyler, Beckham & Sato, 2015). Secondly, true dynamic movement also very rarely takes place at only one joint as is common when using isokinetic testing (Bazyler et al., 2015). Thirdly, true dynamic movement almost always involves the SSC, which changes both the biomechanics and power outputs of the movements (Campos et al., 2002). In a study highlighting the importance of contraction type, 47 NCAA Division III football players performed jump squats with either both eccentric and concentric loading or concentric only loading (Hoffman, Ratamess, Cooper, Jie, Chilakos & Faigenbaum, 2005). They found that the group that included the eccentric component in the jumping improved their power clean and squat maxes as well as their vertical jump significantly more than the concentric only group (Hoffman et al., 2005). These studies support the specificity of contraction force, velocity and type in strength training (Channell & Barfield, 2008; Fatourous et al., 2000; Harris et al., 2000; Hoffman et al., 2005). This may be related to a potential difference in contraction type between the trap-bar jump and the Olympic lifts. Since the Olympic lifts are typically initiated from the floor or blocks and typically dropped from the shoulders, it is essentially free of eccentric contraction; the trap-bar squat-jump includes an eccentric phase of decelerating the bar during both the initiation and completion of the jump when the weight is lowered back to the floor (Haff & Triplett, 2015).

Although many studies look at dynamic movements to look at strength and force changes, using maximal isometric contractions can be very useful as they require very little technical mastery, are highly reliable, and are also very safe (e.g. Hakkinen, Kffomi, & Alen, 1985; Stone et al., 2003; Stone et al., 2004; Thompson et al., 2013). For these reasons, the proposed study will use both isometric and dynamic muscle action to measure changes in power and force output. This is due to the specificity of movement patterns as well as specificity of contraction type (Verkhoshansky & Siff, 2009). Almost all athletic movements occur in a dynamic manner, which include eccentric, isometric and concentric muscle actions (Dietz & Peterson, 2012). Weightlifting movements such as the squat and bench press include all three of these muscle actions, and have been shown to have great impacts on both eccentric and concentric strength, also known as competitive strength (Verkhoshansky & Siff, 2009). This was shown in a foundational study, which found that traditional resistance training increased dynamic strength significantly, but failed to produce more than small improvements in isokinetic strength (Dons, Bollerup, Bonde-Peterson & Hancke, 1976). In the study by Dons et al. (1976), the researchers tracked increases in strength in the back squat and also monitored force output of the knee flexors and extensors using the bio-dex isokinetic device. Although the athletes had significant improvements in the back squat, their isokinetic outputs did not improve by significant amounts (Dons et al., 1976). For this reason, using only isokinetic and/or isometric strength and power testing with athletes likely leaves out a great deal of the picture of complete athletic development (Verkhoshansky & Siff, 2009).

Optimizing Resistance Training

When looking at training in regards to performance enhancement, the question should not be "is the training working?", but "is the training working optimally?" Although there is some evidence that untrained individuals may see excellent progress from sub-optimal training, over time, they are likely to see greater progress from a properly designed periodized training program (Herrick & Stone, 1996; Kraemer, Hakkinen, Triplett-McBride, Fry, Koziris et al., 2003; Kraemer, Ratamess, Fry, Triplett-McBride, Koziris et al., 2000). A few of the most well-known periodization variables are volume, intensity, frequency, duration, exercise selection and the use of special training methods such as plyometric training, contrast training, complex training and cluster sets (Verkhoshansky & Siff, 2009).

There is a distinct difference between "programming" and "periodization" (Stone et al., 2007). Programming includes the numerical variables such as repetitions, sets and percentages of 1-RM. Periodization refers to the order over a time line (macrocycle, mesocycle, microcycle) that specific programming variables are included (Bompa & Haff, 2009). The smallest of these training periods is the microcycle, which typically composes a single week (Stone et al., 2007). Next is the mesocycle, which is a larger chunk of a total program that is typically made up of 2-7 weeks (Stone et al., 2007). Lastly is the overall training plan known as the macrocycle, which can last from a few months to several years (Bompa & Haff, 2009). A very large percentage of the current literature on strength and power research focuses on very short durations of a microcycle, even as a single session, as opposed to a meso- or macrocycle that could be used as a part of a yearly training plan (e.g. Graves, Pollock, Jones, Colvin & Leggett, 1989; Massey, Vincent, Maneval & Johnson, 2005; Pinto, Gomes, Radaelli, Botton, Brown & Boltaro, 2012). This scarcity of longer term studies on training periodization raises some issues as what might work right now, might not work as well down the road due to adaptations.

Traditional Resistance Training

Traditional resistance training has been used for decades with multiple purposes (Haff & Triplett, 2015). These purposes include building/maintaining muscle size and/or strength, improving resistance to injury, changing body composition and increasing power in athletes (Haff & Triplett, 2015). Although most of the traditional methods to resistance training involve moving the body or implement at very high velocities, there is a great deal of research that shows that making an athlete stronger at the slower lifts can lead to some increases in explosiveness by increasing the overall strength potential of an athlete (Fatourous et al., 2000). Overall strength increases from low velocity resistance training have been shown to increase explosiveness in novice subjects without specific explosive training (Thompson, Stock, Shields, Luera, Munayer et al., 2015). Thompson et al. (2015), looked at the vertical jump performances and RFD in 54 college-aged men and women who were non-athlete, resistance training novices. Simply performing the barbell deadlift twice per week for 10 weeks resulted in significant increase in vertical jump height and RFD using isometric knee extensions and flexions (Thompson et al., 2015). These results are in contrast to other studies that have shown no changes or even decreases in RFD from traditional resistance training (Verkhoshansky & Siff, 2009). This is likely due to differences in training status of the participants involved in each study, as participants with a high level of pre-existing strength will have a much harder time improving RFD without specific explosive training such as plyometrics and other high velocity movements (Thompson et al., 2015). The increase in power from traditional resistance training is also due in part to increasing the athletes' strength-to-weight ratio, as the body has a higher proportion of its mass made up of contractile proteins that can create movement and produce mechanical work (Sheppard, Cronin, Gabbett, McGuigan, Etxebarria & Newton, 2008).

Another reason for traditional strength training improving power is that strengthening the core has been shown to allow the athlete to more effectively transfer power throughout the body without loss of energy (Shinkle, Nesser, Demchak, & McMannus, 2012). Traditional resistance training may also, over time, lead to the phosphorylation of myosin regulatory light chains, which makes actin and myosin more sensitive to calcium, both of which increase the force and speed of muscle contractions (Hodgson et al., 2005). Phosphorylation of myosin regulatory light chains also leads to an increase in the rate constant for cross-bridge attachment (Brown & Loeb, 1999). Additional effects of heavy traditional resistance training include an increase in alpha motor-neuron excitability, which allows muscle contractions to occur at a higher frequency (Tillin & Bishop, 2009), and has also been shown to increase twitch tension, increase rate of tension development, and decrease post-stimulus relaxation time (Robbins, 2005).

Although traditional strength training shows improvements in force and power, these programs still have a relatively low correlation to vertical jumping performance due to the relatively slow velocities produced (Baker, 1996). This is supported in a study conducted by Requena et al. (2011), which examined the relationships between traditional back squats and ballistic jump squats on vertical jumping and sprinting (Requena, Garcia, Requena, Villarreal & Cronin, 2011). They found that although both the traditional and ballistic squats had strong relationships with the sprint times, which highlight the need for sufficient lower body strength in sprinting, only the ballistic squat had a strong relationship with jump performance (Requena et al., 2011). One of the reasons for the traditional lifts not translating to explosive movements is the concept that force is calculated as mass x acceleration (Verkhoshansky & Siff, 2009). When the mass being moved is high, the acceleration is often low, which means that the nervous and muscular system are performing differently than during a movement where the mass is low but acceleration is high, like in a body weight jump (Verkhoshansky & Siff, 2009).

Plyometric Training

Explosive strength, which is also known as rate of force development, is the ability of the neuromuscular system to produce the greatest amount of tension in the shortest time possible (Bompa & Haff, 2009). Since explosive strength is always a percentage of maximum strength, increasing maximal strength is a viable strategy for increasing speed-strength especially in beginner and intermediate athletes (Villarreal, Requena & Cronin, 2012). However, explosive strength and maximal strength do not increase at the same rates, so as an athlete becomes more experienced, increasing maximal strength further does not typically increase speed-strength to a significant degree (Stone et al., 2003). Not only does increasing maximal strength further seem to be inefficient for advanced athletes, but the time and recovery abilities needed to increase strength in an athlete who is advanced in weight training is quite substantial (Stone et al., 2003). Furthermore, continuing to focus on maximal strength in an advanced trainee can also potentially be dangerous due to extreme loads and the time needed would likely be better spent on different training strategies (Dietz & Peterson, 2012). One potential training strategy for improving RFD is the use of plyometric, or as Dr. Yuri Verkhoshansky first called it, "shock" training (Verkhoshansky & Siff, 2009). Shock training involves a rapid development of tension in the musculature created by rapidly changing from an eccentric muscular contraction to a concentric action which is seen as a sudden stretch of the muscles followed by a maximal muscle contraction (Carvalho, Mourao & Abade, 2014). This training strategy relies on brief explosive-isometric and eccentric-isometric contraction phases where elastic energy is stored in the muscles and tendons before being released during the concentric movement (Carvalho et al., 2014). Like any type of training, plyometric/shock training can lead to injuries due to its rapid production of tension and speed of movement, however when performed correctly with the proper volume and intensity, high impact movement, such as plyometric training, causes the body to adapt and may lead to stronger bones and joint components (Verkhoshansky & Siff, 2009).

Plyometric movement involves five phases (Verkhoshansky & Siff, 2009). The first phase is the initial momentum phase where the body is moving because of kinetic energy such as dropping from a box (Verkhoshansky & Siff, 2009). Next is the electromechanical delay phase which is the time between the action potentiation/signal for contraction and the contraction itself (Verkhoshansky & Siff, 2009). Thirdly, the amortisation phase is when the kinetic energy and subsequent contraction of muscles to stop the kinetic energy produces a myotatic stretch reflex which leads to explosive eccentric and isometric contractions which cause the breaking of the momentum caused by the kinetic energy from the drop (Verkhoshansky & Siff, 2009). This is followed by the rebound phase which is seen as the release of energy from the elastic components of the musculoskeletal system, which leads to the final momentum phase where the concentric muscle action takes over and a jump is completed (Verkhoshansky & Siff, 2009). In true plyometrics, these five phases must be completed in rapid succession as too great of a pause between the stretch and the final concentric contractions will cause a loss of the stretch reflex (Champman & Caldwell, 1985; Wilson, Elliot & Wood, 1990; Wilson, Elliot & Wood, 1991). However, when done correctly, plyometric training has a great deal of research backing its effectiveness (Villarreal et al., 2012). In a study by Asadi (2013), a group of Division I Iranian college-aged (20.1 ± 0.8 years) basketball players, performed three sets of 15 reps of depth jumps, vertical jumps and long jumps, in two sessions/week for six weeks. The players who completed the plyometric training had significantly greater improvements in their vertical jumps, standing long jumps, T-test and 4x9m shuttle runs when compared to the control group (Asadi, 2013).

Asadi's (2013) results are supported by a great deal of additional research, which has been compiled into a meta-analysis by Villarreal et al. (2012), who compiled data from 26 studies examining the effects of plyometric training on sprint performance. Each study in the meta-analysis needed to be less than 10 weeks in length, but have over 15 plyometric sessions with over 80 jumps/session in order to be included (Villarreal et al., 2012). This meta-analysis showed a very strong relationship between plyometric training and improvements in sprint performance across all populations (Villarreal et al., 2012). This lends strong support to the inclusion of plyometrics in the training of anaerobic dominant athletes (Villarreal et al., 2012). There is also research showing that plyometric training can help to improve gross muscle strength, at least in beginners (Vissing, Brink, Lonbro, Sorensen, Overgaard et al., 2008). Vissing et al. (2008) looked at the differences in muscle adaptations in novice male trainees who performed either traditional resistance training or plyometric training (Vissing et al., 2008). In the beginners, gains in maximal strength were almost identical, however hypertrophy was greater in the resistance training group whereas power measures were significantly higher in the plyometric group (Vissing et al., 2008). As plyometric training is considered a high intensity activity that requires a great deal of CNS activation to produce the high amounts of muscular tension, carefully calculating the volume, frequency and intensity of plyometric training is critical (Verkhoshansky & Verkhoshansky, 2011). This is supported by Villarreal, Gonzalez-

Badillo & Izquierdo (2008) who investigated improvements in CMJs, drop jumps, 20-meter sprints and 1-RM leg press after completing a plyometric training program that was performed either one, two or four days per week for seven weeks. Twice weekly plyometric training produced significantly better results compared to the once a week protocol and very similar results to the four sessions/week protocol (Villarreal et al., 2008). This study demonstrates that more is not always better with plyometric training such as weighted jumps (Villarreal et al., 2008).

Olympic Lifts

The Olympic lifts and their variations have been shown to have a higher degree of effectiveness in improving lower body power compared to traditional resistance training (Channell & Barfield, 2008). Hori et al. (2008) examined the relationship between maximal results in the hang power clean, jumping, sprinting and change of direction in 29 professional Australian male rugby players (21.3 ± 2.7 years) (Hori, Newton, Andrews, Kawamori, McGuigan & Nosaka, 2008). One-RM results of the hang power clean and front squat were recorded as well as the power output during CMJs with either a 40kg barbell or body-weight (Hori et al., 2008). Results in the 5-5 agility test and 20m sprint times were also recorded (Hori et al., 2008). Although there was no relation between the power clean and agility, there were significant positive relationships between the hang power clean, sprint times and vertical jump performance (Hori et al., 2008). These findings led the researchers to conclude that increasing the performance in the hang power clean is likely a beneficial strategy for improving sprint speed and jumping performance (Hori et al., 2008).

The Olympic lifts involve a more ballistic movement of the implements and body of the athlete than the slower lifts such as squats or deadlifts (Seitz, Trajano & Haff, 2014). Although the weights being used are almost always significantly lighter than traditional resistance training, the velocity as well as the explosiveness of the hip, knee and ankle joints have been shown to lead to a favorable increase in jumping power, as well as jumping height in a variety of athletes (Hori, Newton, Nosaka, & Stone, 2005). Not only is the velocity produced during the Olympic lifts closer to the velocity of jumping, but so too is the biomechanical movement (Canavan, Garrett, & Armstrong, 1996). The explosive nature of the Olympic lifts, when combined with traditional resistance training has been shown to increase the excitability of the motor neurons connecting to the faster Type IIA and Type IIX muscle fibers (Aagaard et al., 2000). This allows for faster and more powerful initial muscle contractions (Aagaard et al., 2000). Another reason for Olympic lifts having a positive effect on training for explosive activities such as the vertical jump is that the load can be moved with a great deal of acceleration (Channell & Barfield, 2008). In a traditional squat or deadlift, done with a light enough load to produce significant acceleration, the athlete must actively decelerate the barbell as the lift nears completion to avoid the barbell flying off their back and potentially causing injury (Swinton et al., 2012). This intentional deceleration limits the time that an athlete can accelerate the load, whereas in the Olympic lifts or a weighted jump, the athlete must accelerate the load for as long as possible to obtain optimal results (Swinton et al., 2012).

The Olympic lifts and their variations, as with many forms of resistance training seem to be most effective at training specific qualities at certain percentages of 1-RM (Comfort, Fletcher & McMahon, 2012; Suchomel, Beckham & Wright, 2015; Suchomel, Wright, Kernozek, & Kline, 2014). A great deal of research has been done to determine what relative loads in the Olympic lift variations are ideal for the expression of force and power (Comfort et al., 2012; Suchomel et al., 2015; Suchomel et al., 2014). A study performed by Cormie et al. (2007)

investigated 12 NCAA Division I athletes that included 5 football players, 4 sprinters and 3 long jumpers, averaging 21.4 ± 2.2 years of age, and found that a load of 80% of 1-RM power clean produced the greatest peak power output (Cormie, McCaulley, Triplett & McBride, 2007). A similar study focusing on the hang power clean, had 15 experienced subjects who had hang power cleans of 1.20 ± 0.15 times body weight (Kawamori, Crum, Blumert, Kulik, Childers et al., 2005). The volunteers performed the hang power clean on force plates with weights ranging from 30-90% of 1-RM (Kawamori et al., 2005). Peak power output was optimised when the load was at 70% of 1-RM; however it should also be noted that peak power at 70% was not significantly different than peak power at 50%, 60%, 80% or 90% of 1-RM, which means that peak power can be properly expressed at a large range of relative loads (Kawamori et al., 2005). These findings have been supported by further research as Comfort, Fletcher and McMahon (2012), investigated 19 rugby, soccer and field hockey male athletes who had 1-RM power cleans of 84.52 ± 7.35 kg, found that peak power and peak force occurred at 70% and 80% of 1-RM power clean, respectively. A variation known as the mid-thigh power clean, where the bar is cleaned from boxes has also been investigated (Comfort, Allan & Graham-Smith, 2011a; Suchomel et al., 2015, Suchomel, DeWeese, Beckham, Serrano & French 2014; Suchomel, Wright, Kernozek & Kline, 2014). Comfort, Allan & Graham-Smith (2011a) looked at the ground reaction forces and RFD in 11 elite rugby players performing the power clean, hang-power clean, mid-thigh power clean and the mid-thigh high-pull using 60% of 1-RM power clean. The data showed that the greatest forces and RFD were seen with both the mid-thigh power clean and mid-thigh high pull (Comfort et al., 2011a). This demonstrates that the mid-thigh power clean and/or mid-thigh high pull may be the most optimal variation of the Olympic lifts to perform if one wishes to improve their force producing capabilities (Comfort et al., 2011a). Performing the power clean from the mid-thigh position may also be easier to teach/learn and allow athletes with sub-optimal flexibility to achieve proper technique (Comfort et al., 2011b). The hang high-pull is also supported as being at least as effective in producing power outputs as other variations, as Suchomel et al. (2014) found that the hang high-pull allows the athlete to produce greater power, force and velocity when compared to the hang clean at the same load (Suchomel, Wright, Kernozek, & Kline, 2014). When looking at inexperienced (6-12 weeks of Olympic lifting experience) female athletes with power clean 1-RMs of 51.5 ± 2.65 kg, no significant difference was found in peak power or peak force outputs when performing the power clean, mid-thigh power clean or the hang-power clean (Comfort, McMahon & Fletcher, 2013). This underlines the importance of experience and training status in the demonstration and development of power measures.

From a practical stand point, a lack of athletes with sufficient training experience, especially in the catch phase of the power clean, means that coaches must find ways to train the neuromuscular system through similar movements and velocities that are less difficult to execute properly. A potential solution to this issue is the substitution of the power clean with the hang high-pull as hang high-pull is an exercise that closely mimics the traditional power clean (Suchomel, Wright, Kernozek, & Kline, 2014). As explained by Suchomel et al. (2014), the athlete grasps the bar with a double overhand, shoulder width grip, and stands with the bar until the athlete is up-right (Suchomel, Wright, Kernozek, & Kline, 2014). The athlete, while maintaining a "chest out, shoulders back position", bends at the hips and knees, lowering the bar to just above knee height before changing direction and extending at the hips, knees and ankles while shrugging the shoulders (Suchomel, Wright, Kernozek, & Kline, 2014). The athlete should then use the momentum created, while bending the elbows and keeping the bar as close to the body as possible, to bring the barbell to the approximate height of the sternum (Suchomel, Wright, Kernozek, & Kline, 2014). Due to the absence of the catch phase not only is the movement easier to learn, but greater overload can be achieved due to the ability to perform the movement properly with larger loads and higher rates of acceleration (DiSanto, Valentine & Boutagy, 2015; Suchomel, Wright, Kernozek, & Kline, 2014). Not only can more power be produced, but a greater variety of athletes can benefit from the hang high-pull due to its smaller learning curve when compared to the clean or snatch (Suchomel et al., 2015; Suchomel, Wright, Kernozek, & Kline, 2014; Suchomel, DeWeese, Beckham, Serrano & French, 2014). Evidence from the previous research can lead one to believe that the hang high-pull is at least as effective as the power clean in improving power outputs and is likely much more reliable as it is easier to teach and learn (Suchomel et al., 2015).

Weighted Jumps

To data there has been very little research comparing the effects of weighted jumps and the Olympic lifts. One of the only studies that this author was able to find directly comparing the two training modalities over an intervention period, included 26 recreationally active Australian college students (Teo et al., 2016). The students (18-30 years, 178.7 ± 8.3 cm, 78.6 ± 12.2 kg) completed a six-week intervention where they were assigned to either an Olympic lifting group, which trained movements such as the snatch and hang clean, or the vertical jump training group, which trained movements such as the drop-jump and other plyometric activities (Teo et al., 2016). The researchers collected pre-post data on the squat jump (SJ), countermovement jump (CMJ), drop-jump, 20-meter sprint and the 5-0-5 agility test (Teo et al., 2016). The statistical analysis showed that although the Olympic lifting group saw large increases in SJ and CMJ peak power, there were no statistically significant between group differences for any outcome measure

(Teo et al., 2016). The researchers therefore concluded that the inclusion of either the Olympic lifts or jump training could be used to increase speed, power and agility measures (Teo et al., 2016). Although this study showed that jump training may be interchangeable with the Olympic lifts, it did not examine weighted jumps. Including weighted jumps in Teo's et al. (2016) study may have affected the results as a larger external load would have likely increased factors such as motor-unit recruitment and resulted in further increases in force and power development (Verkhoshansky & Siff, 2009). The only other published paper comparing the Olympic lifts to jumps was performed by Tricoli et al. (2005). In their study, 32 active male volunteers completed an eight-week intervention where they completed training consisting of high-pulls, power cleans, and clean and jerks, or double-leg hurdle hops, alternated single-leg hurdle hops, single-leg hurdle hops, and drop jumps (Tricoli et al., 2005). Ten and 30-meter sprints, SJs, CMJs and half squats were measured before and after the intervention period (Tricoli et al., 2005). The data show that the Olympic lifting group experienced significant ($p < 0.05$) improvements in the 10-meter sprint, SJ, CMJ and half squat, while the jumping group only significantly ($p < 0.05$) improved in the CMJ and half squat (Tricoli et al., 2005). The researchers concluded that the Olympic lifting group improved in more tasks compared to the jumping group, as the Olympic lifting exercises utilize external loads (Tricoli et al., 2005). These external loads helped to develop greater levels of strength compared to the unloaded jumping group, which means that the Olympic lifts may be useful in developing a greater spectrum of physical abilities compared to jump training alone (Tricoli et al., 2005).

Although the studies by Teo et al. (2016) and Tricoli et al. (2005) are possibly the only intervention focused, peer-reviewed, refereed journal articles comparing the Olympic lifts to jumping, there has been additional research conducted on the topic. Oranchuk and Jordan

(2013), examined peak power (W/kg) outputs between un-weighted jumps, weighted jumps and the power clean in 10 national level Canadian weightlifting athletes (Oranchuk & Jordan, 2013). The volunteers were instructed to perform five un-weighted countermovement jumps, five weighted countermovement jumps with an additional 80kg loaded on a trap-bar, and a 1-RM power clean. Data were analysed using a Pearsons product correlation coefficient and it was found that both weighed jumps ($r = 0.88$) and the power clean ($r = 0.74$) had a significant ($p < 0.05$) positive relationship with un-weighted jumps (Oranchuk & Jordan, 2013). The researchers concluded that the weighted trap-bar jump may be more specific to the un-weighed jump, and that weighted jumps may be more effective for improving un-weighed jumping compared to the power clean (Oranchuk & Jordan, 2013).

As the trap-bar (hex-bar) is a relatively new piece of equipment, there is a lack of research surrounding it, although that is starting to change. Thomas, Tobin and Delahunt (2015), investigated the relationship between vertical jump height, acceleration and peak power output in the trap-bar jump squat (TBJS). Seventeen Australian professional rugby players (21.3 ± 1.3 years old, 98.6 ± 9.4 kg, 1.85 ± 0.06 meters, box squat 1-RM = 187.2 ± 17.1 kg) performed 10-meter and 20-meter sprints, three body-weight CMJs and three TBJSs at a weight that was pre-determined to produce the greatest force (Thomas et al., 2015). The researchers found significant correlations to TBJS for 10-meter sprint ($r = 0.70$), 20-meter sprint ($r = 0.75$) and CMJ ($r = 0.80$), respectively (Thomas et al., 2015). The researchers concluded that the athletes who were able to produce the highest peak power numbers in the TBJS were also the athletes with the fastest sprints and highest jumps (Thomas et al., 2015). The TBJS has also been found to be a more effective means of producing the greatest peak power measurements in 29 rugby union athletes (26.3 ± 4.6 years old, 182.4 ± 6.8 cm, 94.5 ± 13.1 kg; 153.7 ± 20.3 kg 1-RM squat) when compared to weighted jumps with a barbell on the back (Swinton et al., 2012). The participants completed jumps with 0%, 20%, 40% and 60% of their 1-RM back squat with the weight added either by a straight barbell across their shoulders, or loaded on a trap-bar (Swinton et al., 2012). Across all loads, greater peak power measures were seen with the trap-bar jumps compared to the barbell (Swinton et al., 2012). This shows that increasing the external load in jumping movements is likely more effectively done via handheld means (McKenzie, Brughelli, Gamble & Whatman, 2014).

Turner, Tobin and Delahunt (2015) examined the optimal loading range for the trap-bar jump squat for the development of peak power in 17 professional male rugby players (21.3 ± 1.3 years old, 98.6 ± 9.4 kg, 1.85 ± 0.06 meters, box squat 1-RM = 187.2 ± 17.1 kg). They examined the peak power produced with loads of 10, 20, 30 and 40% of the athletes' 1-RM parallel box squat (Turner et al., 2015). The data showed that the greatest peak power measures were seen with trap-bar jumps with 20 and 30% of the weight of the parallel box squat 1-RM (Turner, Tobin & Delahunt, 2015). In a study by Swinton et al. (2011), 19 Scottish male powerlifters (30.2 ± 5.6 years, 181.5 ± 4.8 cm, 114.5 ± 22.3 kg; barbell deadlift 1-RM: 244.5 ± 39.5 kg; trap-bar deadlift 1-RM: 265.0 ± 41.8 kg, with 13.7 ± 5.2 years of powerlifting experience) performed deadlifts using either a trap-bar or a straight barbell using loads ranging from 10-80% of their 1-RM straight bar deadlift. The deadlifts were done on force plates and peak force, peak velocity and peak power values were found to be higher during the trap-bar deadlift when compared to the straight-bar across all loads (Swinton et al., 2011). The authors hypothesized that having the weight closer to the center of mass of the athletes allowed them to exert more of their force into the ground (Swinton et al., 2011). Although an athlete may have specific qualities that would allow them to excel in a specific task, they may be limited by their biomechanical leverages and therefore unable to exert their potential force due to long movement arms (Nigg et al., 2000). By bringing the center of the external mass closer to the athletes' center of gravity, more athletes can train effectively (Nigg et al., 2000).

Safety when training should always be a factor to consider in exercise prescription. Swinton et al. (2011) found that the peak movement angles with the trap-bar were more acute in the ankles and knees and more obtuse at the hips when compared to the barbell deadlift. This allows the athlete to maintain a more vertical torso position which shifts the force from the lower back onto the lower body, which means that the trap-bar deadlift is likely a superior means of training the lower body and potentially carries less risk of lower back injury (Swinton et al., 2011). The trap-bar lifts are also done with a neutral grip, where the hands are facing each other (Swinton et al., 2011), which has been shown to produce less strain on the wrist, elbow and shoulder joints compared to supinated or pronated grip variations (Durall, Manske, & Davies, 2001). Different grip positions have also been shown to activate the muscles of the back and arms differently, therefore incorporating different grips may help to avoid overuse injuries (Youdas, Amundson, Cicero, Hahn, Harezlak & Hollman, 2010). In addition, most people have more grip strength when the wrist in placed in a neutral position when compared to either the pronated or supinated position (Marley & Wehrman, 1992). The ability to have a more secure grip when using the trap-bar is further supported by the handles being fixed, which is much easier to grip than the straight bar, which tends to roll in the hands making the grip more difficult (Chiu, 2010). The trap-bar lifts can also be quite simple to teach and is often easier for athletes to learn when compared to the barbell back squat, deadlift or power clean (Gentry, Pratt & Caterisano, 1987).

Strength & Power Testing

Isometric Force Measures

The use of isometric muscle contraction in the measurement of strength and power has become popular in research (e.g. Haff, Carlock, Hartman, Kilgore, Kawamori et al, 2005; Haff, Ruben, Lider, Twine & Cormie, 2015; Haff, Stone, O'Bryant, Harman, Dinan et al., 1997; McGuigan, Newton, Winchester & Nelson, 2010; Painter, Haff, Ramsey, Triplett, McBride et al., 2011). This is due at least in part to the ability of isometric force measures to be easily repeatable as well as valid means of estimating dynamic performances (Haff et al., 1997). Isometric tests such as the Isometric Mid-Thigh Pull (IMTP), are also one of the only ways for an athlete to safely perform a maximal voluntary muscular action (MVMA) (Haff et al., 1997). This is because in a lift that involves dynamic muscle action, the strength and force curves change rapidly throughout the movement due to changes in joint angles and leverage (Verkhoshansky & Siff, 2009). These changes throughout a range of motion can significantly and quickly affect the intensity of muscle contraction making data collection difficult (Fleck & Kraemer, 2004). Furthermore, maximal isometric contractions are typically safer than eccentric or concentric contractions as the joint movements are kept to a minimum (Nigg et al., 2000).

Another positive to using isometric testing as opposed to dynamic means such as vertical jump, is that the results are not affected by the subjects' body weight (Thompson, Ryan, Sobolewski, Smith, Akehi et al., 2013). When performing athletic tasks such as jumping or sprinting, the athlete may produce more force, but have very mild increases, or even decreased performance from a gain in body mass (Thompson et al., 2013). The same can occur in the opposite manner as an athlete may have lost explosive ability, but their jump or sprint performance may have improved due to a loss in body mass (Verkhoshansky & Verkhoshansky, 2011). Due to the variability of body mass and its effect on dynamic performance, absolute strength measures such as isometric peak force (I-PF) can be used to more accurately record and track force production over time (Verkhoshansky & Siff, 2009). However, though I-PF can correlate strongly to dynamic force and power, it cannot always accurately predict jump height or distance (Haff et al., 1997; Haff et al., 2005; Nuzzo, McBride, Cormie & McCaulley, 2008). This is demonstrated by Thompson et al. (2013), who examined the relationship between rapid isometric torque development (RITD) and vertical jump performance in 12 linemen and 19 non-linemen Division I American football players (20.6 ± 1.5 years, 106.7 ± 22.0 kg, 183.4 ± 8.6 cm). They compared results from isometric testing of knee flexors and extensors on a Bio-Dex and found very poor correlations between the isometric tests and vertical jump height until they normalised the statistical analysis for the athletes' body weights (Thompson et al., 2013). Once body weight was included, the researchers concluded that the athletes with the greatest isometric force characteristics typically had the highest vertical jumps (Thompson et al., 2013).

Khamoui et al. (2011) also found similar trends although they tested both dynamic and isometric strength using many exercises (Khamoui, Brown, Nguyen, Uribe, Coburn et al., 2011). Multi-joint means of measuring isometric force were implemented via the isometric back squat (IBS) and the IMTP, and dynamic forces were determined via hang high-pulls and vertical jumps (Khamoui et al., 2011). Khamoui et al. (2011), found similar results to Thompson et al. (2013) in that isometric and dynamic force characteristics were only strongly correlated when an athlete's body mass was taken into consideration. There was a high degree of individualization in the results (Khamoui et al., 2011). For example, Khamoui et al. (2011) stated that "subjects with the greatest and least relative isometric peak force (IPF) attained the second slowest and fastest barbell peak velocities, respectively." The authors concluded that these individual variations in results are at least in part due to different training methods of the subjects who were not from a homogenous population (Khamoui et al., 2011). This means that in order for results to be consistent, it is likely optimal for subjects to have experience performing both isometric and dynamic testing exercises before data collection (Khamoui et al., 2011).

One potential disadvantage of using isometric force-time characteristics for assessing potential improvements in dynamic movement is the fact that the joint angles, kinetic patterns and body position between the two must be fairly similar for a significant carry over to occur (Wilson, Murphy & Walshe, 1996). This was demonstrated by Blazevich, Gill & Newton (2002), who found that an isometric squat with a knee angle of 90 degrees had a strong correlation for a back squat performed to 90 degrees of knee bend. These results were expanded upon by Bazyler et al. (2015), who examined the relationship between isometric force-time characteristics in the isometric squat with knee angles of 90 and 120 degrees and the dynamic parallel back squat or partial back squat. The data showed that isometric performance at 90 degrees of knee flexion correlated strongly with dynamic performance at 90 degrees and that isometric performance at 120 degrees of knee flexion correlated strongly with dynamic performance at 120 degrees (Bazyler et al., 2015). However, performance between the two knee angles was not strongly correlated (Bazyler et al., 2015). The athletes who were the best performers at one knee angle, were not always the top performers at the other knee angle (Bazyler et al., 2015). This leads back to specificity of movement and means that when testing isometric force characteristics, it is paramount to choose joint and body angles that closely match the dynamic performance that may be important in an athlete's sport or event (Fleck & Kraemer, 2004). As many sports involve the vertical jump as a performance measure, and many other sports involve movements that are similar to a vertical jump, determining knee angles in isometric performance that strongly correlate to vertical jumping performance is important. Marcora and Miller (2000) looked at isometric force-time characteristics on a leg press at 90 and 120 degrees of knee flexion and their relationship to the CMJ. They found that isometric performance at 120 degrees could accurately predict vertical jump height, however isometric performance at 90 degrees of flexion did not (Marcora & Miller, 2000). Since then, several studies have shown that knee angles of 120-145 degrees during isometric tasks are most likely to result in greater peak forces and have a greater carry over to a majority of athletic tasks, such as jumping (Haff et al., 2005; Haff et al., 2008; Haff et al., 2015; Kawamori et al., 2005; Kawamori et al., 2006; Marcora & Miller, 2000).

Although there are several methods of using isometrics in athletic testing, such as the isometric squat and the isometric leg press, the most commonly used method in recent literature appears to be the IMTP (Haff et al., 2015; Haff et al., 2008; Nuzzo et al., 2008; West, Owen, Jones, Bracken, Cook et al., 2011). The IMTP is executed by pulling on an immovable barbell in a power-rack where the barbell is set as a height where the athletes' knees are bent between 120-145 degrees when they are grasping the barbell (Haff et al., 2015; West, Owen, Cunningham, Cook & Kilduff, 2011). The athlete, typically standing on force plates, then pulls as hard and fast as possible on the bar for 5 seconds which pulls themselves down on to the force plates (Haff et al., 2015). This allows the tester to gather several ground reaction force measures such as peak force (PF), RFD, peak rate of force development (PRFD) and impulse (Haff et al., 2015). Additionally, testers can look at force production at different times into the effort, most commonly being 0–30, 0–50, 0–90, 0–100, 0–150, 0–200, and 0–250 milliseconds (Haff et al., 2015). This can be useful as different athletic tasks require force to be produced at different rates and times in order for optimal performance to be achieved (Verkhoshansky & Siff, 2009).

One well-established reason for the use of the IMTP is that it can provide a strong correlation to dynamic performances (West, Owen, Jones, Bracken, Cook et al., 2011). West, Owen, Jones et al. (2011) examined the relationship between the IMTP, 10-meter sprint time and CMJ in 39 professional male rugby players. The researchers looked at PF, PRFD and force at 100 milliseconds and found that once expressed relative to the athlete's body mass, all the isometric force-time metrics had significant correlations to the dynamic performances (West, Owen, Cunningham et al., 2011). In an earlier study by Stone et al. (2004), they determined that sprint cyclists who were able to produce greater PRFD via the IMTP were able to produce greater power in the vertical jump and Wingate power test (Stone et al., 2004). Although RFD and PRFD have been shown to have high correlations to dynamic performance, gross measures of maximal strength such as isometric peak force (IPF) have also been shown to correlate strongly with many measures of dynamic performance (Stone et al., 2003). In a study with 11 (five male, six female) NCAA Division II throwers, the IMTP was tested along with dynamic mid-thigh pulls, barbell snatch and throwing distance over an eight-week training cycle (Stone et al., 2003). The researchers looked at PF and PRFD in the IMTP and although they found a small relationship between PRFD and the dynamic performance measures, PF was most closely related to the dynamic movements (Stone et al., 2003). These applications for the IMTP have also been confirmed by more recent research by Wang and colleagues (2016), where 15 male members of a high level university rugby team (20.67 ± 1.23 years, 1.78 ± 0.06 meters and 86.51 ± 14.18 kg) completed a 1-RM squat, maximal IMTPs, 40-meter sprints, and the pro-agility and 5-10-5 agility tests (Wang et al., 2016). The researchers collected PF, PRFD and force at 30ms, 50ms, 90ms, 100ms, 150ms, 200ms and 250ms. The data show that the 1-RM squat had a strong, statistically significant ($p < 0.05$) relationship to force at 90-250ms ($r = 0.595$-0.748) and peak force ($r = 0.866$), while sprint times over the first 5 meters in the 40-meter sprint were significantly ($p < 0.05$) correlated with PRFD (Wang et al., 2016). These results suggest that the IMTP could potentially be used as a means of monitoring progress in athletes over a training period as well as a means of predicting dynamic sport performances (Stone et al., 2003; Wang et al., 2016).

Countermovement & Squat Jumps

Jumps involve the athlete explosively jumping from a static (squat jump) or dynamic (countermovement jump) position with or without an external load (Waller et al., 2013). During a squat jump (SJ), the athlete commonly holds a semi-squat position for approximately three seconds before jumping as high as possible; this can be done with or without the arms being used to assist the jump, depending on if the researcher/coach wants to look at total body power or attempt to isolate the lower body (Radenkovic & Stankovic, 2012). This same process occurs in the countermovement jump (CMJ) except that the athlete begins in the standing position and then quickly drops into the semi-squat position before immediately reversing directions and jumping (Radenkovic & Stankovic, 2012). The countermovement jump allows the athlete to use the stretch shortening cycle to jump more powerfully and therefore higher (Waller et al., 2013). This added power output from the CMJ does not appear to be affected by adding additional loads as the myoelectric activity was found to be no different as long as the stretch shortening cycle was used (Bosco, Tihanya, Komi, Fekete & Apor, 1982). This means that maximal motor unit recruitment can be caused by ballistic muscle action at many levels of force production and muscle shortening velocities (Bosco et al., 1982). The study performed by Bosco et al. (1982) also found that performance in the SJ is almost entirely determined by the contractile qualities of the muscles whereas the CMJ performance is strongly affected by the release of stored elastic energy in the stored elastic component (SEC) that is built during the rapid eccentric movement that is quickly followed by the concentric movement in the jump.

Testing both the SJ and CMJ in athletes can be useful to determine where their training status lies and can give the coach an estimate of where to focus training for the upcoming block (Verkhoshansky & Siff, 2009). If the two jump types are very close in height then the athlete has enough of a strength surplus to jump higher, but they must practice using the stretch shortening cycle (Verkhoshansky & Verkhoshansky, 2011). If the two jumps are very far apart the athlete likely has a strength deficit and lacks the base muscular strength needed to help them produced sufficient force (Verkhoshansky & Verkhoshansky, 2011). Both the SJ and CMJ have been performed with external resistance such as elastic bands (Gooyers, Beach, Frost & Callaghan, 2012), barbells, dumbbells (Waller et al., 2013) and trap-bars (Waller et al., 2013). These types of jumps have been shown to improve lower body power when compared to traditional resistance training programs and work similarly to the Olympic lifts as very high velocities and powerful extension of the hips, knees and ankles are possible (Carvalho, Mourao & Abade, 2014). Jumps, like the Olympic lifts, can be used in conjunction with traditional resistance training to increase the excitability of the motor neurons allowing the muscles to tap into the faster, more explosive, type IIA and type IIX fibers (Komi, 2003) which can give power athletes a distinct advantage (Verkhoshansky & Siff, 2009).

Jumps such as the CMJ and SJ have been used heavily as a means of identifying talent in athletes as well as progress from specific training programs (Stone et al., 2007). This is because jumping movements are of high importance in many team and individual sports (Verkhoshansky & Siff, 2009). CMJs and SJs can also be related to total and lower body power, depending on if arm swing is used (Radenkovic & Stankovic, 2012) and can therefore be used to predict success in sports where power is important, but where little to no vertical displacement occurs (Loturco, D'Angelo, Fernandes, Gill, Kobal et al., 2015). Jumping when compared to maximal back squats or other resistance training means of determining power or force is also very quick, easy and safe to perform and therefore offers a distinct advantage for the sport and/or strength & conditioning coach (Stone et at., 2007). The measuring of vertical jump performance is becoming easier and more quantifiable with the development of equipment such as the "Opto-Jump" and "SmartJump" contact mat (Glatthorn, Gouge, Nussbaumer, Stauffacher, Impellizzeri & Maffiuletti, 2011; Reeve & Tyler, 2013). However, it should be noted that contact mats such as the "SmartJump" have yet to be perfected and carry some potential error as the algorithms involved include flight time which can be altered if the athlete tucks their legs prior to landing if certain athletes have very high vertical jumps (Whitmer, Fry, Forsythe, Andre, Lane et al., 2015). These contact mats also do not have the ability to measure outputs such as power, force, velocity, RFD, PRFD or impulse, unlike the current gold standard of force plates/platforms (Reeve & Tyler, 2013). These additional measurements outside of simple vertical displacement are important as vertical displacement is affected by several variables that may or may not be important in different sports/activities (Verkhoshansky & Siff, 2009). These variables include body weight (Nuzzo et al., 2008; Thompson et al., 2013) and jump technique (Stone et al., 2007), both of which may lead to poor vertical displacement despite relatively high force outputs. In a study by McLellan, Lovell and Gass (2011), 23 active male participants (23.0 ± 3.9 years), who were not experienced in resistance or explosive training, performed CMJs and SJs on a force plate. PRFD, PF, and time to peak force (TPF) were measured during each of the jumps (McLellan et al., 2011). The researchers determined that PF and PRFD were the most important contributors to vertical jump height regardless of body weight (McLellan et al., 2011). This shows that PRFD during a vertical jump may be more important than the jump height itself when assessing and monitoring athletes of different body weights and sports (McLellan et al., 2011).

Another variable that can be determined from the force-time curve of a jump is impulse (Kirby, McBride, Haines & Dayne, 2011; Mizuguchi, 2012; Mizuguchi, Sands, Wassinger, Lamont & Stone, 2015). Impulse refers to the area under the force-time curve and can be calculated in the different phases of a vertical jump which include: the amortization phase, where the force is produced to stop the decent from the pre-load; the propulsion-acceleration phase, where the athlete is beginning to accelerate their body upwards; and the propulsion-deceleration phase, where the force from the propulsion-acceleration phase begins to drop off as the athlete starts to leave the ground (Mizuguchi, 2012). The net positive impulse is calculated from the propulsion-acceleration phase and is typically used to determine both velocity at takeoff and vertical jump height (Kirby et al., 2011; Mizuguchi, 2012). Since peak force is altered greatly by jump technique, such as the degree of knee flexion that an athlete drops to, and since mean force can include the amortization phase and the propulsion-deceleration phase, both of which have little to no impact on the height of the jump, net positive impulse looks to be more a more valid and reliable metric for recording and monitoring performance in the vertical jump (Kirby et al., 2011; Mizuguchi, 2012). A study by Kirby et al. (2011) used impulse and other force-time curve characteristics to predict vertical jump height. Ten college-aged male volunteers (23.3 ± 1.5 years, 176.7 ± 4.5 cm, 84.4 ± 10.1 kg) with at least two years of jumping experience, performed CMJs and SJs to 15, 30, 45, 60, 75 and 90 degrees of knee flexion, while on force plates that recorded peak power, peak force, peak velocity jump height and net vertical impulse (Kirby et al., 2011). The researchers found that while peak force has a negative relationship to jump height for both the CMJ and SJ, net positive impulse had a strong, significant relationship with height in the CMJ (r = 0.9337) and SJ (r = 0.925) (Kirby et al., 2011). The researchers also found that jump height found by calculating impulse was more reliable than through other calculations, which means that calculating jump height via impulse is likely the most valid and reliable means of comparing performance over time. Although there is a lack of studies focusing on impulse, the fact that it is directly used to calculate variables such as takeoff velocity and vertical jump height make it a key metric in tracking and monitoring athletic progress.

Summary

Total and lower body strength and power play pivotal roles in the success of a wide variety of athletes (Nibali et al., 2013). Therefore, it is of great importance to both sport coaches as well as strength and conditioning professionals to find and seek out optimal means of developing strength and power in their athletes. There are two primary goals that an optimal training plan typically includes when strength and power development is the primary focus. The first of these goals is to increase the size of the muscle fibers (Haff & Triplett, 2015). This hypertrophy of the musculature increases the CSA of a muscle and has been shown to have a dramatic effect on the strength and power that a muscle can produce (Howley & Powers, 2012). The second goal of many programs is to improve the neuromuscular function and thus increase intra- and intermuscular coordination, activate the fast-twitch fibers sooner, and increase rate coding (Verkhoshansky & Siff, 2009). These adaptations not only build upon hypertrophic adaptations in that they increase strength and power, but they also appear to be most effective in increasing the RFD which is arguably more important than developing maximal strength (Verkhoshansky & Siff, 2009). Popular means of working towards these goals include traditional resistance training, plyometric training and the use of Olympic lifts (Stone et al., 2007).

Traditional resistance training has been used for quite some time with the goal of increasing, speed, strength, power and resistance to injury by both increasing lean mass and forcing positive adaptations in the neuromuscular system of athletes (Haff & Triplett, 2015). Although traditional resistance training has repeatedly been shown to be effective, the lack of movement pattern and speed of movement specificity has often left much to be desired (Stone et al., 2007). In order to more closely mimic competition movements/velocities, overload the SSC and increase RFD, the use of plyometrics have been used in the physiological development of athletes since at least the 1960s (Verkhoshansky & Siff, 2009). As with traditional resistance training, plyometrics have led to positive effects in strength and power athletes (Verkhoshansky & Siff, 2009). Olympic lifts and their variations, as well as weighted jumps have only relatively recently become the "go-to" exercises for many coaches and strength and conditioning professionals. This is likely because they borrow qualities from both traditional resistance training and plyometrics in that there can be a significant external load, and they involve explosive ballistic movements that have a great deal of movement pattern specificity with many athletic movements (Stone et al., 2007).

The most popular of the Olympic lifting variations is the barbell power clean, which has been shown to have a significant carry over to athletic movements like the vertical jump and sprint speeds (Channell & Barfield 2008; Hoffman et al., 2009; Hori et al., 2000; Hori et al., 2005). Although the power clean can be a great tool, it can be difficult to teach and learn, and many athletes may have flexibility and coordination limitations that may prevent safe and effective use of this power movement (Fees & Martin, 1997). In an effort to find a more widely accessible high velocity training movement, exercises such as the HHP have been studied as a potential substitute for the full power clean movement (e.g. Channell & Barfield, 2008; Comfort et al., 2011a; Comfort et al., 2011b; Comfort et al., 2013). Several studies have shown the HHP to be at least, if not more, effective than the power clean for producing power (Comfort et al., 2011a; Comfort et al., 2011b; Comfort et al., 2013; Suchomel, DeWeese, Beckham, Serrano & French, 2014) and by removing the catch portion, a greater number of athletes can safely perform the movement (DiSanto et al., 2015; Suchomel, Wright, Kernozek & Kline, 2014; Suchomel et al., 2015).

Another exercise type that may be an excellent substitution of the power clean and other Olympic lifting variations, are weighted jumps. Weighted jumps are similar to the Olympic lifts in that they involve an external load, but also include a high degree of movement pattern specificity to competition movements (Verkhoshansky & Siff, 2009). There are several ways of loading a weighted jump such as jumping with a barbell on the shoulders, or by holding dumbbells or using trap-bar (Waller et al., 2013). The advantage of a trap-bar is that much greater loads can be used when compared to dumbbells (Swinton et al., 2011), and because the load is closer to the athlete's center of mass, more force can be developed when compared to the same load in the form of a barbell (McKenzie et al., 2014; Swinton et al., 2012).

At the present time, the most common exercise choice for measuring power in athletes is the vertical jump (Verkhoshansky & Siff, 2009). This is due to several reasons which include ease of use, low risk of injury, movement pattern specificity to many sports, and a high reliability for measuring key athletic qualities such as dynamic force, power and RFD (Loturco et al., 2015; McLellan et al., 2011). Although vertical jump testing can be a great way of assessing dynamic movement, vertical jumps may not be an effective means of tracking changes in maximal strength (Stone et al., 2007). This is because jumping can be highly technical, involves changing joint angles, and the fact that changes in vertical jump height can be heavily influenced by body mass (Nuzzo et al., 2008; Thompson et al., 2013). A highly valid, reliable and safe means of measuring maximal force output and RFD while using multiple joints and sport specific positions is the IMTP (e.g. Bazyler et al., 2015; Beretic et al., 2013; Haff et al., 2008; McGuigan et al., 2010). Therefore, it is hypothesized that the combination of vertical jump testing and the IMTP can be both safe and effective for inclusion in a testing battery for a wide variety of athletes when measuring both dynamic and maximal force and power. Thus, the purpose of this study is to compare the relatively well known and widely used Olympic lifts and their variations, specifically the hang high-pull with the much less widely used trap-bar jump squat, in the development of vertical jump performance and isometric force-time characteristics. The goal of the study is to provide evidence to show that the much easier to learn TBJS is as effective as the widely used, but more difficult to learn HHP, for training power and force in athletes.

Chapter III

Procedures

Introduction

Working on the improvement of lower body power and force-time characteristics is an important aspect of overall strength and conditioning for most athletes. Classic methods of training the lower body include exercises such as squats and deadlifts which are staples in many strength and conditioning programs (Haff & Triplett, 2015). These exercises can improve muscular hypertrophy, reduce injuries, lead to improved body composition and increase relative and total strength (Haff & Triplett, 2015). However, they may leave something to be desired when it comes to the development of acceleration and velocity (Baker, 1996). When compared to movements such as the Olympic lifts and their variants, traditional resistance training such as the squat and deadlift are typically performed with much slower velocities (Hoffman et al., 2005). Although Olympic lifts and their variations have been shown to be very effective in improving explosive power, they can be difficult to teach and learn which can lead to poor technique, sub-par results and injury (Fees & Martin, 1997). The difficulties in teaching proper technique are compounded in large settings such as collegiate training centers when it is not uncommon to have a single coach responsible for the development and safety of a great number of athletes (Haff & Triplett, 2015). Therefore, looking for alternative means to train at a similar velocity and movement pattern as the Olympic lifts should be explored further. One such exercise that fits this description is the trap-bar jump squat (TBJS) (Canavan et al., 1996; Kawamori et al., 2003; Swinton et al., 2011; Thomas et al., 2015; Turner et al., 2015; Waller et al., 2013).

Approach to the problem

This study focused on the effectiveness of the TBJS compared to the traditional barbell hang high-pull (HHP) for improving lower body force and power. In order to test this, the athletes performed either the TBJS in combination with a traditional resistance training program or the HHP combined with the same, volume equated, traditional resistance training program. Progress was measured via countermovement (CMJ) and squat jump (SJ) performance and the isometric mid-thigh pull (IMTP) to determine changes in dynamic and isometric force and power characteristics. The goal was to determine if either the TBJS or HHP have a significant advantage over the other when developing force, power and rate of force development (RFD) in NCAA Division II collegiate swimmers.

Setting

All testing took place in the Human Performance Lab in the Human Performance and Physical Education building on the East Campus of Adams State University, which is located at 7544 feet above sea level. All training for this study took place in the Plachy Hall weight-room, located in the Athletic Department of Adams State University. Adams State University is a NCAA Division II University located in Alamosa Colorado, USA.

Population

The participants in this study consisted of 21 (N=10 males, N=11 females) NCAA Division II collegiate swimmers. Due to several dropouts, not related to the actual study, the completed study consisted of 18 (N=8 males, N=10 females) volunteers. These 18 participants had a mean age, height, body weight and body fat percentage of 20.8 ± 3.2 years, 172.6 ± 8.8 cm, 69.0 ± 10.4 kg and 15.6 ± 6.2%, respectively. They were asked to volunteer prior to any testing, and filled out and signed the proper consent forms once the researcher received IRB approval from the Adams State University Institutional Review Board (Appendix A & B). Since the research design only altered a small part of the participant's regular training program, and all training and testing took place during each athlete's normal training schedule.

Instrumentation

Standard resistance training equipment, which can be found in nearly all collegiate training centers, was used for the training program. All barbells used for the HHP were Werksan (Ankara, Turkey) "Olympic" bars and all trap-bars used for the TBJS were Samson (Las Cruces, New Mexico) trap-bars. The HHP and TBJS were loaded with Werksan Olympic bumper plates and were performed on Samson weightlifting platforms.

The IMTP was done by setting up an immovable Samson "Power Bar" underneath the immovable spot catches of a Samson power rack. The athletes then attach themselves to the immovable bar using Iron-Mind (Nevada City, California) "quick release" lifting straps. During the IMTP the athletes stood on two PASCO-Scientific (Roseville, California) dual-axis force plates. The athlete's knee angle was measured by a Prestige medical (Northridge, California) goniometer. All IMTP data was collected and analyzed with PASCO-Scientific's "Capstone" data collection and analysis software to look at relative peak force (N/kg), relative force (N/kg) at 50, 100, 150, 200 and 250 ms, and peak rate of force development (N/s).

Both vertical jump tests (CMJ and SJ) were done while standing on two PASCO-Scientific dual-axis force plates. During the CMJs and SJs, the athletes also wore a Myotest-T (Sion, Switzerland) accelerometer. All CMJ and SJ force plate data were collected with PASCO Scientific's "Capstone" data collection software and was analyzed using a custom

Mathwords^{Tm} (Natick, Massachusetts), "Matlab" data analysis software to find relative peak power (W/kg), and jump height (cm) as determined by take-off velocity (m/s).

Research Design

This study included a ten-week intervention that included both pre- and post-testing before and after the intervention period, with two groups of randomly selected (via Excel spread sheet) groups of athletes and equal numbers of each gender in each group. Additionally, each group had an equal number of sprint, middle distance and long distance swimmers, to allow for an equal amount of endurance and speed/power athletes in each group. Group one performed the TBJS as their primary high-velocity training exercise during the ten-week intervention, whereas group two performed the HHP during the same time frame. Both groups were instructed not to change their dietary, sleep, social or training routines during the ten-week intervention. All participants were instructed to fill out a dietary log and abstain from supplements on the first day of pre-testing and to match their intake on the post-testing days. After the participants completed the ten-week training intervention, they were given four days off from strenuous training before performing the post-intervention testing. The pre- and post-tests included the isometric mid-thigh pull (IMTP), and both the countermovement jump (CMJ) and squat jump (SJ) on force plates. The participants also wore an accelerometer to improve accuracy and validity of velocity, force and power readings (Cassartelli, Muller & Maffiuletti, 2010; Hansen, Cronin & Newton, 2011).

All subjects in the study had been resistance training for at least one year and had been training the HHP, TBJS and IMTP under the instruction and supervision of a Certified Strength & Conditioning Specialist (CSCS) for a minimum of six weeks prior to the start of the intervention. This pre-study familiarization phase was designed to install safe and effective form as poor technique may not only be unsafe, but may also decrease the potential improvement in power and force gained from the interventions (Fees & Martin, 1997).

All subjects completed the same total volume (sets/reps) for their primary exercises (HHP or TBJS), as well as the same total volume for the traditional resistance training exercises during the ten-week training period (Appendix C). Control of total volume was critical to prevent improvements in one program due to the athletes simply performing more volume, and thus having greater stimulus for the body to adapt (Haff & Triplett, 2015). Throughout the ten-week intervention, intensity was gradually increased while the change in volume through reps and sets occurred in an accumulation, transmutation, realization, type fashion with a sharp reduction in total volume every fourth week to avoid staleness and overtraining (Poliquin, 1988; Stone et al., 2007). The second de-load occurred the week prior to post-testing to ensure that residual fatigue did not compromise performance (Stone et al., 2007).

Before approval from the Adams State University IRB had been secured (Appendix A), the researcher confirmed support from the athletic department at Adams State University. The athletes who volunteered for the study filled out and signed the necessary informed consent forms (Appendix B). The coaches and athletes of the ASU swim team were briefed on the design and purpose of the study prior to any testing.

Athletes had their basic anthropometric data taken, which included height, weight and skinfolds, which were entered into the ISAK body composition software (Norton & Olds, 2004) to calculate body fat percentages, lean mass and fat mass. Weights and heights were taken by the same SECA brand scale and stadiometer during pre- and post-testing. All measurements were taken by the researcher, a certified level-1 ISAK anthropometrist, using the ISAK body composition sites and software (Norton & Olds, 2004). All skinfold measurements were taken using Harpenden skinfold calipers (Dykes, Francis & Marks, 1976). All anthropometric data were taken at the same time of day to avoid fluctuations in height (Buckler, 1978), hydration and stomach volume, which could affect total body weight and therefore body composition and relative power and force results (Horber, Thomi, Casez, Fonteille & Jaeger, 1992; Wang, Deurenberg, Wang, Pietrobelli, Baumgartner & Heymsfield, 1999).

To ensure the safety of the athletes, and the reliability of the results, proper technique of the CMJ, SJ, IMTP, TBJS, HHP, TBDL and power clean, and proper use of lifting straps was taught to the participants in the six weeks leading up to the testing and intervention (Fees & Martin, 1997; Haff & Triplett, 2015). The pre-testing took place on two non-consecutive days. Day one consisted of CMJ and SJ testing and began with a general 10-minute warm-up focusing on increasing total body temperature and activating the nervous system to prevent injury and improve performance (Appendix D) (Haff & Triplett, 2015). After the general warm-up the athletes performed five CMJs and five SJs in a randomized order, on force plates which were set to sample at 500Hz (Dos' Santos, Jones, Kelly, McMahon, Comfort & Thomas, 2016) in order to measure relative peak power (W/kg), and take-off velocity (m/s) which was used to determine vertical displacement. The athletes performed five jumps of each type so that poor jumps could be eliminated, and only the highest SJ and CMJ performed were used for data analysis. The five CMJs were separated by 15 seconds. Once the CMJs were completed, the participants rested for three minutes before completing five SJs which were also separated by 15 seconds. The peak numbers for each variable were taken for statistical analysis. The athletes also wore an accelerometer unit on their left hip to further improve the accuracy and reliability of the jump height (cm) and relative peak power (W/kg) (Cassartelli et al., 2010; Hansen et al., 2011). Athletes were instructed to keep their hands on their hips, but not directly over the accelerometer, to eliminate extra vertical propulsion from the upper-body. Athletes were verbally instructed when to step onto the force plates and remain as still as possible so that the force plates could accurately recognize the athlete's downward force before beginning the jumps (Hall, Fleming, Dolan, Millbank & Paul, 1996). In the CMJ, the athletes were instructed to simply perform a maximal vertical jump by dropping to a depth of 90 degrees of knee flexion, and in one consistent movement, jumping as high as possible. For the SJ, the athletes were instructed to drop to 90 degrees of knee flexion and hold that position while the tester counts out loud "3, 2, 1, jump!". Once the tester shouts "jump!" the athlete jumps as high as possible without dipping or pre-loading further. To insure subject-to-subject reliability and remove much of the stretch reflex, the tester used a stop-watch and waited for three (3) seconds to elapse before instructing the athlete to jump (Verkhoshansky & Verkhoshansky, 2011).

Forty-eight hours after the first testing session, the athletes performed the isometric mid-thigh pull (IMTP) while standing on force plates, set at a sampling rate of 500 Hz (Dos' Santos et al., 2016), to measure their relative isometric peak force (N/kg), relative force at 50, 100, 150, 200 and 250 ms, and peak rate of force development (N/s). This was performed in a power-rack set-up, using straps to prevent neural inhibition and safety issues from loss of grip (Haff et al., 1997; Kawamori et al., 2006). A stiff barbell was attached under the immovable power-rack catches and the force plates were raised or lowered by adding or removing dense rubber matting in order to ensure that each athlete's knee angle was set at between 130-140 degrees of flexion as confirmed by a goniometer (Haff et al., 2015). The knee angle and thickness of rubber matting were recorded to ensure the same position was achieved for post-testing. The athletes were instructed to wear non-slip, hard and/or thin soled shoes that would not slip or greatly compress which could affect the results of the test. The athletes then performed a dynamic warm-up designed to decrease injury risks and encourage a proper mood state for resistance training (Appendix D) (Haff & Triplett, 2015). The athletes were then given two submaximal isometric pulls at 50% and 75% of maximal perceived exertion to further warm-up and to familiarize themselves with the test (Bayzler et al., 2015). Once the warm-up was complete, the athlete attached themselves to the bar with lifting straps, with their hands at shoulder width. The athletes were instructed to have their thighs as close to the bar as possible and to keep their back straight and up-right to prevent injury and allow for optimal biomechanical leverage (Haff et al., 2015). The athletes were instructed to "pull as hard and fast as possible" (Haff et al., 2015). Once the athlete was ready, the tester counted down "3, 2, 1, Pull!" The athletes then pulled as hard and fast as possible on the bar forcing their feet into the ground for 5 seconds, or until force began to drop off, before the tester told them to stop (Haff et al., 2005). Each athlete was given two attempts with three minutes of rest between attempts. If the two trials differed by more than 250 Newtons, then a third trial was given (Haff et al., 2005). The trial with the highest peak force was used for statistical analysis. All athletes were encouraged to the same degree by the tester to attempt to match motivation levels between athletes as to not affect testing results between athletes or between testing sessions (Gould, Weinberg & Jackson, 1980; Shelton & Mahoney, 1978; Weinberg, Gould & Jackson, 1980; Yerkes & Dodson, 1908).

Forty-eight hours after the pre-testing and prior to the intervention, the athletes were split randomly into either the HHP or the TBJS group ensuring that each intervention has an equal number of male and female participants and equal numbers of sprint, middle distance and long distance swimmers. Over the week between pre-testing and the beginning of the intervention, the athletes in the HHP group performed the power clean from the floor up to a 1-RM using safe form determined by a CSCS. The testing protocol for determining 1-RM power clean started with a dynamic warm-up designed to increase body temperature and encourage a proper mood state for resistance training (Appendix D) (Haff & Triplett, 2015). The athletes proceeded to start their specific warm-up by practicing proper technique with light weights starting with an empty bar and individually working up in weight in 2-10 kilogram increments as instructed by an experienced CSCS (Suchomel et al., 2015). The athletes rested 3-5 minutes between attempts based on individual feelings of fatigue (Haff & Triplett, 2015). The athletes continued in this fashion until they could not complete a power clean with safe form. After the 1-RM power clean had been determined for each athlete, specific percentages of power clean 1-RM were calculated to determine the load range that each athlete used for the duration of the intervention (Appendix C).

Forty-eight hours after the pre-testing, and before starting the intervention, the athletes in the TBJS performed a trap-bar deadlift (TBDL) 1-RM using safe form determined by a CSCS. The testing protocol for determining 1-RM TBDL started with a dynamic warm-up designed to increase body temperature and encourage a proper mood state for resistance training (Appendix D) (Haff & Triplett, 2015). The athlete proceeded to start their specific warm-up by practicing proper technique with light weights starting with an empty bar and individually working up in weight in 5-20 kilogram jumps as instructed by an experienced CSCS (Turner et al., 2015). The athletes rested 3-5 minutes between attempts based on individual feelings of fatigue. The athletes continued in this fashion until they could not complete a TBDL with safe form. Each maximal attempt was supervised by a CSCS to ensure proper form and safety. After the 1-RM TBDL had been determined for each athlete, specific percentages of 1-RM TBDL were calculated to determine the load range for the TBJS that each athlete used for the duration of the intervention (Appendix C).

Both groups trained their respective high velocity resistance training movement (HHP or TBJS) twice per week at the beginning of their regular resistance training session. For the HHP group, the first session of each of the weeks consisted of (sets x reps) 4x4 at 75%, 5x5 at 75%, 6x5 at 75%, 3x5 at 80%, 5x5 at 80%, 6x4 at 85%, 6x3 at 87.5%, 4x3 at 90%, 4x4 at 80% and 3x3 @ 75% of power clean 1-RM, respectively (Appendix C). For the TBJS group, the first session of each of the ten weeks consisted of 4x4 at 20%, 5x5 at 20%, 6x6 at 20%, 3x5 at 25%, 5x5 at 25%, 6x4 at 30%, 6x3 at 32.5%, 4x3 at 35%, 4x4 at 25% and 3x3 at 20% of TBDL 1-RM, respectively (Appendix C).

For both groups, the second sessions of each week followed a cluster-like loading protocol where each rep of each set was separated by 10-15 seconds of rest. This protocol was selected to be followed because cluster sets have been shown to allow athletes to maintain higher velocities and force outputs throughout a set and to aid in staving off staleness throughout a training cycle (Stone et al., 2007). A single cluster set of "2+1" consisted of 2 repetitions of the lift, followed by 10-15 seconds of rest before completing the final rep. For the HHP group, the cluster-set and rep scheme for each of the ten weeks consisted of 4x2+2 at 80%, 5x2+2 at 80%, 5x2+2+1 at 80%, 3x2+2 at 85%, 4x2+2 at 85%, 5x2+1 at 90%, 6x1+1 at 92.5%, 4x1+1 at 95%, 4x3+2 at 80% and 2+1+1+1 @ 75% of power clean 1-RM, respectively (Appendix C). For the TBJS group, the cluster-set and rep scheme for each of the ten-weeks consisted of 4x2+2 at 25%, 5x2+2 at 25%, 5x2+2+1 at 25%, 3x2+2 at 30%, 4x2+2 at 30%, 5x2+1 at 35%, 6x1+1 at 37.5%, 4x1+1 at 40%, 4x3+2 at 25% and 2+1+1+1 @ 20% of Trap-Bar Deadlift 1-RM, respectively (Appendix C). During the first four weeks, each set was separated by 90 seconds of rest, while each set during the second four weeks was separated by 120 seconds of rest to allow for more complete neurological recovery as the intensity (percentage of 1-RM) increased (Haff & Triplett, 2015) (Appendix C).

During the ten-week intervention, each group performed the exact same resistance and dry-land training program as the rest of their respective team with the exception of performing either the HHP or the TBJS as the primary high velocity resistance training movement (Appendix C). Both groups completed the same volume of sets and reps in all aspects of their training programs and form was watched closely by a qualified strength and conditioning coach to ensure safety and reliability. Additionally, both groups performed three sets of the IMTP at 50%, 75% and 100% of perceived maximal exertion with straps at the end of each Friday's weight-room session throughout the intervention to help them become comfortable with performing maximal isometrics and with properly utilizing straps. The first four weeks of the intervention focused on accumulation of volume, where total volume was increased each week, with week four serving as a de-load week where intensity is maintained, but total reps are reduced by 40% (Poliquin, 1988; Stone et al., 2007). The next four weeks consisted of a transmutation phase which included lower repetitions and increasing intensities. Week eight served as a de-load week where intensity was maintained and total volume was reduced by 30% (Poliquin, 1988; Stone et al., 2007). This was followed with a two-week realization phase which consisted of lower volumes and intensities in order to reduce cumulative fatigue and peak (Stone et al., 2007). At the end of the ten-week intervention, the participants were given four days off from strenuous activities so that residual fatigue was less likely to affect post-testing results and so full adaptations could have a chance to take place (Stone et al., 2007). Once the athletes returned from their four-day break, the post-testing was performed, following the exact same procedures as the pre-test. Pre- and post-tests were also be performed at the same time of day as each team's regular resistance training to avoid fluctuations in circadian rhythm which could have affected performance/results (Chtourou, Ammar, Nikolaidis, Karim, Souissi et al., 2015; Chtourou, Driss, Souissi, Gam, Chaouachi & Souissi, 2012). All sessions were supervised to ensure that the proper loads, reps and sets were used, and attendance was taken for every session of the intervention. To be included in the results, each athlete must have been present for at least 24 of the 30 intervention sessions. If a session was missed, an athlete was allowed to make up missed sessions within the same week as the missed session. Refer to Appendix E for an outline of the complete time line for the 10-week study.

Reliability

Based on the procedures for the experiment, there should have been a high level of reliability. Other researchers will be able to duplicate the study if they have the means to set up an IMTP station and have access to force plates and accelerometers. Force plates such as the ones used in this study are considered the gold standard for collecting force (N), rate of force development (RFD), and take-off velocity (m/s) in both the jumps and the isometric mid-thigh pull (Beretic et al., 2013; Haff et al., 2008; Haff et al., 2005; Haff et al., 1997; Murphy & Wilson, 1996; Painter et al., 2011). Additionally, the estimating vertical jump from flight time using the myotest accelerometer has been shown to be a reliable and accurate means of collecting vertical jump height (cm) (Cassartelli et al., 2010; Hansen et al., 2011). The jump tests of the CMJ and SJ have also been shown to be reliable means of assessing anaerobic power (Verkhoshansky & Siff, 2009). The use of comparable Division II athletes should yield similar results if the same testing protocols and equipment are used by other researchers. Similar intervention duration would also need to be followed as a shorter or longer intervention could cause different results. The most important aspect that needed to be kept consistent would be the loading protocol for the HHP and TBJS interventions. Any significant changes to the loading protocols for the HHP or TBJS could result in different pre-to-post test results.

The training programs used in this study should be reliable as they were written and supervised by a CSCS with eight years of coaching experience. This ensured safe and effective training. Body composition was be measured by a certified ISAK level-1 anthropometrist (Norton & Olds, 2004) using Harpenden skinfold calipers (Dykes et al., 1976). Weights and heights will be taken with a SECA brand electronic scale and stadiometer. All testing on the IMTP occurred at the same knee angles as measured by a goniometer and all fell between 130 and 140 degrees of knee flexion, as shown to be reliable in previous studies (Bazyler, et al., 2015; Beretic et al., 2013; Fry et al., 1992; Haff et al., 2008; Haff et al., 2005; Haff et al., 2015; Haff et al., 1997; Kawamori et al., 2006; McGuigan et al., 2010; McGuigan & Winchester, 2008; Murphy & Wilson, 1996; Painter et al., 2011). All jump testing was done to 90 degrees of knee flexion and was strictly monitored by the researcher to avoid changes in jump technique between pre-post-testing.

Validity

The data collected from the experiment should be valid based on the type of participants, exercises, instrumentation and testing protocols that were selected. The use of the Olympic lifts and hang high-pulls have been shown to be valid means of increasing force and power production in athletes (Channell & Barfield, 2008; Comfort et al., 2011a; Comfort et al., 2011b; Cormie et al., 2007; DiSanto et al., 2015; Hori et al., 2011; Hori et al., 2008; Kawamori et al., 2005; Suchomel, DeWeese, Beckham, Serrano & French, 2014; Suchomel, Wright, Kernozek, & Kline, 2014). Weighted jumps, such as the TBJS, have been shown to be valid means of increasing force and power production in athletes (McKenzie et al., 2014; Swinton et al., 2011; Swinton et al., 2012; Turner et al., 2011).

Including only trained NCAA Division II athletes should allow the maintenance of safe and effective form and prevent any deviation in the loading protocols for either intervention. This study also included a period of technique acquisition for the IMTP, CMJ and SJ prior to any testing so that changes in IMTP and jump metrics will be due to physiological adaptations and were not affected by technical or psychological changes (Haff et al., 2005).

The IMTP has been shown to be a valid means of measuring peak force and RFD (Bazyler, et al., 2015; Beretic et al., 2013; Fry et al., 1992; Haff et al., 2008; Haff et al., 2005; Haff et al., 2015; Haff et al., 1997; Kawamori et al., 2006; McGuigan et al., 2010; McGuigan & Winchester, 2008; Murphy & Wilson, 1996; Painter et al., 2011). The CMJ and SJ with the use of force plates and Myotest accelerometers have been shown to be valid means of measuring force, power, velocity and jump height (Komi, 2003; Loturco et al., 2015; McLellan et al., 2011; Nuzzo et al., 2008; Radenkovic & Stankovic, 2012; Thompson et al., 2013; Verkhoshansky & Siff, 2009; Waller et al., 2013).

The training programs used in this study were written by a CSCS with eight years of coaching experience and are considered valid training programs to improve strength and power in athletes. The entire training program was also closely supervised by the same experienced CSCS, which ensured safe and effective training. Body composition was measured by the same certified ISAK level-1 anthropometrist (Norton & Olds, 2004) using the same set of calibrated Harpenden skinfold calipers (Dykes et al., 1976). Weights and heights were taken with the same SECA brand electronic scale and stadiometer. All testing on the IMTP occurred at the same knee angles as measured by a goniometer and fell between 130 and 140 degrees of knee flexion, as shown to be valid in previous studies (Bazyler, et al., 2015; Beretic et al., 2013; Fry et al., 1992; Haff et al., 2008; Haff et al., 2005; Haff et al., 2015; Haff et al., 1997; Kawamori et al., 2006; McGuigan et al., 2010; McGuigan & Winchester, 2008; Murphy & Wilson, 1996; Painter et al., 2011). All jump testing was done to 90 degrees of knee flexion and was strictly monitored by the researcher to avoid changes in jump technique between pre- and post-testing.

Statistical Analysis

Data was collected and recorded using Excel spreadsheets. Statistical analysis of the data was accomplished using a paired samples t-test to evaluate differences between pre- and post-test in all dependent variables regardless of intervention type. Differences between intervention types were analysed using independent t-tests. Data were checked for normality with Shapiro-Wilk tests and the assumption of homoscedasticity was analysed using Levene's test. Statistical differences were considered significant at $p < 0.05$. Data was analyzed using the 2013 SPSS Version 22 statistical analysis software. The independent variables for this study were the use of either the HHP or the TBJS as the athlete's primary high velocity training exercise for the duration of the ten-week intervention. The dependent variables in this study included relative peak force (N/kg), relative force (N/kg) at 50, 100, 150, 200 and 250 ms and peak rate of force development (N/s) in the IMTP, and relative peak power (W/kg) and jump height (cm), determined by take-off velocity (m/s), in the CMJ and SJ. Only the peak numbers for the isometric mid-thigh pull and the highest of the five SJs and five CMJs were used in statistical analysis.

Chapter IV

Results

A total of 21 swimming athletes (N = 10 male, N = 11 female) volunteered for the study. Due to dropouts, a total of 18 athletes (N = 8 male, N = 10 female) completed the entire 10-week intervention. Of the dropouts, two athletes quit the swim team during the intervention and one athlete experienced a back injury from an un-related accident and therefore was not able to complete the minimum number (24/30) of sessions required to be included in the results. Data was analyzed using SPSS (Version 22, 2013) statistical analysis software. Statistical evaluation of the data was accomplished using both dependent paired t-tests and independent samples t-tests. The dependent paired t-test was used to analyze the pre- to post-changes from the intervention across all participants, whereas the independent samples t-test was used to analyse the between group differences between the two experimental conditions (hang high-pull group vs trap-bar squat jump group). Statistical differences were considered significant at $p \leq 0.05$. The independent variables for this study were the use of either the HHP or the TBJS as the athlete's primary high velocity training exercise for the duration of the 10-week intervention. The dependent variables in this study included relative peak force (N/kg), relative force (N/kg) at 50, 100, 150, 200 and 250 ms and peak rate of force development (N/s) in the IMTP, and relative peak power (W/kg) and jump height (cm), determined by take-off velocity (m/s), in the CMJ and SJ. Only the peak numbers for the isometric mid-thigh pull and the highest of the five SJs and five CMJs were used in statistical analysis. All data were checked for assumptions of normality with Shapiro-Wilk tests.

Subject Characteristics

At baseline, the participants as a whole had a mean (± SD) age, height, body weight and body fat percentage of 20.8 ± 3.2 years, 172.6 ± 8.8 cm, 68.2 ± 11.1 kg and 15.6 ± 6.2%, respectively. The HHP group (n = 4 male, n = 5 female) consisted of participants with a mean age, height, body weight and body fat percentage of 20.2 ± 2.4 years, 174.0 ± 6.2 cm, 71.9 ± 9.3 kg and 16.5 ± 4.9%, respectively. The TBJS group (n = 4 male, n = 5 female) consisted of participants with a mean age, height, body weight and body fat percentage of 21.4 ± 3.0 years, 171.2 ± 5.4 cm, 64.4 ± 11.8 kg and 15.2 ± 5.8%, respectively. None of the anthropometric measures were significantly ($p > 0.05$) different between or within groups.

At the end of the study, the HHP group's body weight and body fat percentage dropped to 69.9 ± 7.4 kg and 14.8 ± 5.2%, respectively. The TBJS group's body weight and body fat percentage dropped to 63.6 ± 12.7 kg and 13.9 ± 5.8%, respectively. The changes in the anthropometric measures were not statistically ($p > 0.05$) different between or within groups.

Vertical Jump Characteristics

Shapiro-Wilk tests showed that assumptions for normality were not violated as the test was found to be non-significant for all dependent variables and differences between each variable pre- to post-intervention. Levene's test for quality of variances showed that all differences displayed homoscedasticity except countermovement jump peak power (W/kg), which was accounted for in the independent t-test analysis (Appendix F: Independent Samples Test).

The vertical jump metrics used in this study included relative peak power (W/kg) and vertical jump height (cm) in both the squat jump (SJ) and countermovement jump (CMJ). All vertical jump metrics significantly ($p < 0.05$) increased over time in both groups. When analyzed as a single group with all subjects together, SJ relative peak power increase from 43.52 ± 8.64 W/kg to 45.81 ± 9.34 W/kg (M = 2.32, SE = 0.82), 95% C.I. [0.59, 4.04] was significant t(17) = 2.84, p = 0.011 (Appendix F: Descriptive Statistics). Mean relative peak power in the CMJ increased from 41.94 ± 9.15 W/kg to 45.60 ± 9.36 W/kg (M = 3.66, SE = 1.07), 95% C.I. [1.40, 5.92] following the 10-week intervention. This increase was significant t(17) = 3.42, p = 0.003 (Appendix F: Descriptive Statistics). Vertical SJ height across all participants increased from 27.41 ± 7.97 cm to 29.73 ± 8.61 (M = 2.52, SE = 0.73), 95% C.I. [0.99, 4.05]. This increase was significant t(17) = 3.47, p = 0.003 (Appendix F: Descriptive Statistics). Vertical CMJ height increased from 25.89 ± 7.83 cm to 29.64 ± 8.70 cm (M = 3.86, SE = 0.59), 95% C.I. [2.63, 5.10]. This increase was significant t(17) = 6.60, p < 0.001 (Appendix F: Descriptive Statistics).

When comparing the HHP and TBJS groups, there were no significant ($p > 0.05$) differences in the improvements found in any of the vertical jump metrics (Appendix F: Independent Samples Tests). In the SJ, relative peak power in the HHP group increased by 1.2 ± 3.8 W/kg, whereas the TBJS group's relative peak power in the SJ increased by 3.5 ± 2.8 W/kg (Table 1). Although the difference (M = 2.29, SE = 1.58), 95% C.I. [1.06, 5.65] was not statistically significant t(16) = 1.45, p = 0.166, statistical analysis determined that the effect size of each intervention on SJ relative peak power was moderate (r = 0.33) (Table 1). In the CMJ, relative peak power in the HHP group increased by 3.08 ± 2.33 W/kg, whereas the TBJS group's relative peak power in the CMJ increased by 4.24 ± 6.25 W/kg (Table 1). The difference (M = 1.16, SE = 2.22), 95% C.I. [3.55, 6.10] was not statistically significant t(16) = 0.52, p = 0.61, and effect size of each intervention on CMJ relative peak power was low (r = 0.12)

(Table 1). In the SJ, vertical jump height in the HHP group increased by 1.7 ± 3.1 cm, whereas the TBJS group's vertical jump height in the SJ increased by 3.4 ± 2.5 cm (Table 1). Although the difference (M = 1.72, SE = 1.43), 95% C.I. [1.32, 4.76] was not statistically significant t(16) = 1.20, p = 0.247, statistical analysis determined that the effect size of each intervention on SJ vertical jump height was moderate (r = 0.30) (Table 1). In the CMJ, vertical jump height in the HHP group increased by 3.9 ± 3.1 cm, whereas the TBJS group's vertical jump height in the CMJ increased by 3.8 ± 1.7 cm (Table 1). The difference (M = 0.03, SE = 1.21), 95% C.I. [2.53, 2.59] was not statistically significant t(16) = 0.28, p = 0.978, and effect size of each intervention on CMJ jump height was low (r = 0.02) (Table 1).

Table 1. Changes in Vertical Jump and Isometric Force Time Characteristics from 10-Week Intervention

Variable	Hang High-Pull	Trap-Bar Jump Squat	p-value	Effect Size ($\hat{r}$)
SJ Peak Power (W/kg)	+1.2 ± 3.8	+3.5 ± 2.8	0.17	0.33
SJ Height (cm)	+1.7 ± 3.1	+3.4 ± 2.5	0.25	0.30
CMJ Peak Power (W/kg)	+3.1 ± 2.3	+4.2 ± 6.3	0.61	0.12
CMJ Height (cm)	+3.9 ± 3.1	+3.8 ± 1.7	0.98	0.02
IMTP Peak Force (N/kg)	+3.3 ± 2.0	+3.9 ± 2.8	0.65	0.12
PRFD (N/s)	+486 ± 440	+655 ± 753	0.56	0.14
Force at 50 ms (N/kg)	+2.2 ± 1.5	+2.7 ± 2.5	0.67	0.03
Force at 100 ms (N/kg)	+2.1 ± 1.7	+3.0 ± 2.5	0.39	0.14
Force at 150 ms (N/kg)	+3.4 ± 2.2	+2.9 ± 2.3	0.71	0.21
Force at 200 ms (N/kg)	+3.4 ± 2.1	+3.7 ± 2.5	0.78	0.05
Force at 250 ms (N/kg)	+2.8 ± 2.4	+3.8 ± 2.5	0.43	0.13

SJ = Squat jump; CMJ = Countermovement jump; IMTP = Isometric mid-thigh pull
Reported as mean ± SD * denotes significant difference (p < 0.05)

Tables 2 and 3 show all individual data for subjects in each group. From these tables, some large deviations within each group can be observed. For example, although the mean improvement in relative peak power and jump height for the HHP group in the SJ was 1.16 W/kg and 1.65 cm respectively, subject 1 improved by 8.82 W/kg and 7.5 cm respectively (Table 2). Instances of large individual variations were also apparent in the TBJS group's SJ outputs. For example, subject 15 increased SJ peak power and jump height by 9.39 W/kg and 9.7 cm respectively, whereas subject 18 only saw an increase in SJ peak power and SJ jump height of 0.79 W/kg and 0.3 cm, respectively (Table 2). Similar observations can be made in the CMJ outputs as subjects 11 and 14 improved by peak power 12.07 and 15.53 W/kg respectively, while the group's mean improvement was 4.24 W/kg (Table 3).

Table 2. Individual Subject Data for Squat Jumps Pre- and Post- 10-Week Intervention

Subject	SJ Peak Power (W/kg)			SJ Jump Height (cm)		
	Pre	Post	Change	Pre	Post	Change
HHP						
1	48.96	57.78	+8.82	33.3	40.4	+7.2
2	54.10	50.91	-3.20	37.3	37.9	+0.6
3	47.71	49.84	+2.13	29.7	33.8	+4.1
4	54.56	56.75	+2.19	41.9	44.0	+2.1
5	35.67	37.98	+2.31	21.8	22.3	+0.4
6	29.34	31.27	+1.93	14.8	17.6	+2.8
7	31.39	32.97	+1.58	16.3	19.0	+2.7
8	37.27	32.92	-4.35	22.3	19.0	-3.3
9	38.65	37.74	-0.91	22.3	20.6	-1.7
Mean	41.96	43.13	+1.16	26.63	28.29	+1.65
TBJS						
10	46.74	47.53	+0.79	32.2	33.8	+1.6
11	59.34	61.32	+1.98	38.7	43.7	+5.0
12	50.32	53.19	+2.87	39.3	40.2	+0.6
13	41.24	42.71	+1.47	24.7	26.8	+2.1
14	51.56	56.16	+4.60	33.8	35.9	+2.2
15	35.30	44.69	+9.39	23.8	33.5	+9.7
16	35.60	37.88	+2.28	21.4	24.2	+2.8
17	44.51	50.83	+6.32	24.0	29.9	+5.9
18	41.07	42.53	+1.46	25.1	25.4	+0.3
Mean	45.07	48.54	+3.46	29.22	32.6	+3.35

Table 3. Individual Subject Data for Countermovement Jumps Pre- and Post- 10-Week Intervention

Subject	CMJ Peak Power (W/kg)			CMJ Jump Height (cm)		
	Pre	**Post**	**Change**	**Pre**	**Post**	**Change**
HHP						
1	51.27	56.10	+4.83	32.7	38.5	+5.8
2	54.24	56.55	+2.31	35.1	37.3	+2.2
3	47.91	50.14	+2.23	29.4	33.5	+4.1
4	53.74	58.27	+4.53	36.8	44.9	+8.1
5	37.66	39.45	+1.79	24.2	25.1	+0.9
6	29.38	35.08	+5.70	15.4	22.9	+7.5
7	30.44	35.03	+4.59	15.0	19.9	+4.9
8	34.88	31.88	-2.00	18.8	16.8	-2.0
9	35.23	38.99	+3.76	18.2	21.6	+3.4
Mean	41.64	44.61	+3.08	25.07	28.95	+3.88
TBJS						
10	52.40	50.81	-1.59	31.7	32.5	+0.8
11	49.58	61.65	+12.07	42.8	48.0	+5.2
12	53.26	52.52	-0.74	29.2	35.6	+6.4
13	47.19	49.79	+2.60	31.2	35.1	+3.9
14	34.40	49.93	+15.53	30.2	35.4	+5.2
15	33.13	40.48	+7.35	22.3	26.3	+4.0
16	30.09	33.60	+3.52	19.4	21.8	+2.4
17	40.42	42.54	+2.13	23.6	27.5	+3.9
18	39.68	37.02	-2.66	19.2	22.0	+2.8
Mean	42.24	46.59	+4.24	27.73	31.57	+3.84

Isometric Force-Time Characteristics

Shapiro-Wilk tests showed that assumptions for normality were not violated as the test was found to be non-significant for all dependent variables and differences between each variable pre- to post-intervention. Levene's test for quality of variances showed that all differences displayed homoscedasticity (Appendix F: Independent Samples Test).

The isometric mid-thigh pull (IMTP) metrics used in this study included relative peak force (N/kg), peak rate of force development (N/s) and relative force at 50, 100, 150, 200 and 250 ms. All IMTP metrics significantly ($p < 0.05$) increased in both groups. When analysed as a single group including all subjects, mean relative peak force in the IMTP increased from 33.30 ±

5.73 N/kg to 36.92 ± 5.44 N/kg (Appendix F: Descriptive Statistics). Peak RFD increased from 4646.28 ± 1481.95 N/s to 5216.50 ± 1612.61 N/s following the 10-week intervention (Appendix F: Descriptive Statistics). Relative force at 50, 100, 150, 200 and 250 ms increased from 29.16 ± 4.73 N/kg, 29.90 ± 4.88 N/kg, 30.37 ± 4.90 N/kg, 30.52 ± 5.18 and 31.03 ± 4.96 to 31.59 ± 4.69 N/kg, 32.42 ± 4.75 N/kg, 33.51 ± 5.00 N/kg, 34.80 ± 5.16 N/kg and 34.30 ± 5.01 N/kg respectively (Appendix F: Descriptive Statistics), following the 10-week intervention.

When comparing the HHP and TBJS groups, there were no significant ($p > 0.05$) differences in the changes found in any of the isometric force-time characteristics. For relative peak force, the HHP group increased by 3.3 ± 2.0 N/kg, whereas the TBJS groups relative peak force increased by 3.9 ± 2.8 N/kg (Table 1). The difference ($M = 0.66$, $SE = 1.43$), 95% C.I. [2.37, 3.69] was not statistically significant $t(16) = 0.46$, $p = 0.65$, and effect size of each intervention on isometric relative force was low ($r = 0.12$) (Table 1). For peak RFD, the HHP group increased by 486 ± 440 N/s, whereas the TBJS group increased peak RFD by 655 ± 753 N/s (Table 1). The difference ($M = 169.78$, $SE = 286.08$), 95% C.I. [436.68, 776.23] was not statistically significant $t(16) = 0.59$, $p = 0.56$, and effect size of each intervention on peak RFD was low ($r = 0.14$) (Table 1). For relative force across the five time bands, the HHP group increased their force at 50, 100, 150, 200 and 250 ms by 2.2 ± 1.5 N/kg, 2.1 ± 1.7 N/kg, 3.4 ± 2.2 N/kg, 3.4 ± 2.1 N/kg and 2.8 ± 2.4 N/kg respectively (Table 1). The TBJS group increased their force at 50, 100, 150, 200 and 250 ms by 2.7 ± 2.5 N/kg, 3.0 ± 2.5 N/kg, 2.9 ± 2.3 N/kg, 3.7 ± 2.5 N/kg and 3.8 ± 2.5 N/kg respectively (Table 1). Statistical significance was not met ($p \geq 0.388$) for any of these time bands and the effect sizes were all low ($r \leq 0.21$) (Table 1).

As with the vertical jump characteristics, there were noticeable individual variations in the IMTP results. Table 4 shows individual data for each group. In the HHP group, subject 1 increased relative peak isometric force by 7.47 N/kg, while subject 4 experienced a reduction in relative peak force of 3.9 N/kg. The same was found to be true for peak RFD in the HHP group as subject 3 experienced an increase in peak RFD of 1245 N/s, whereas subject 8 saw a decrease in peak RFD of 53 N/s during the 10-week intervention (Table 4). This trend is also evident in the TBJS group as subject 17 increased relative peak isometric force by 7.72 N/kg, while subject 11 experienced a reduction in relative peak force of 0.70 N/kg. The same was found to be true for peak RFD in the TBJS group as subject 13 experienced an increase in peak RFD of 1734 N/s, whereas subject 12 saw a decrease in peak RFD of 674 N/s during the 10-week intervention (Table 4).

Table 4. Individual Subject Data for Isometric Mid-Thigh Pull Pre- and Post- 10-Week Intervention

Subject	Peak Force (N/kg)			Peak RFD (N/s)		
	Pre	Post	Change	Pre	Post	Change
HHP						
1	36.45	43.92	+7.47	5681	6627	+946
2	33.51	38.71	+5.20	4945	5208	+263
3	34.53	40.38	+5.85	6062	7307	+1245
4	40.90	37.00	-3.90	6106	6590	+484
5	23.76	27.89	+4.13	3216	3657	+442
6	25.21	28.77	+3.56	3215	3360	+145
7	28.73	31.33	+2.60	4205	4884	+682
8	34.95	36.04	+1.09	6908	6855	-53
9	33.09	36.66	+3.57	4724	4942	+219
Mean	32.35	35.63	+3.28	5007	5492	+486
TBJS						
10	35.18	36.16	+0.98	4919	6383	+1464
11	47.16	46.47	-0.70	7272	7775	+503
12	37.25	41.12	+3.87	5555	4881	-674
13	35.13	39.91	+4.78	4474	6208	+1734
14	30.41	35.36	+4.94	2262	2562	+300
15	34.02	40.49	+6.47	4755	5697	+941
16	34.00	39.75	+5.75	3465	4680	+1215
17	30.70	38.46	+7.72	3897	4147	+250
18	24.50	26.14	+1.64	1972	2134	+161
Mean	34.27	38.21	+3.94	4286	4941	+655

Chapter V

Discussion

Introduction

The purpose of this study was to examine the effects of a 10-week intervention focusing on either weighted jumps, via the trap-bar jump squat (TBJS), or Olympic lifts, via the hang high-pull (HHP), on explosive athletic measures. Total work was equated for the 10 weeks between groups in order to control for training load. The tests used to measure the effects of the intervention were the countermovement (CMJ) and squat jumps (SJ) to measure relative peak power (W/kg) and jump height (cm), and the isometric mid-thigh pull (IMTP) to measure isometric relative peak force (N/kg), peak rate of force development (N/s) and relative force at five time bands (N/kg). The original hypothesis was that there would not be any statistically significant ($p > 0.05$) differences between groups, but that the TBJS group would improve more than the HHP group for the vertical jump measures, and the HHP group would improve more than the TBJS group for the isometric force measures. There was a statistically significant ($p < 0.05$) improvement for all measures in both groups over the 10-week intervention, however no between group differences were found to be significant ($p > 0.05$). Although there were no statistically significant between group differences, the TBJS tended to experience greater improvements in SJ relative peak power and jump height, which were found to have medium effect sizes of $r=0.33$ and $r=0.30$, respectively (Table 1). These medium effect sizes mean that although the increase in SJ relative peak power ($p = 0.166$) and jump height ($p = 0.247$) did not quite reach statistical significance, the differences between groups could potentially result in large performance increases (Field, 2014). Upon closer inspection of the raw data, the TBJS group (3.5 ± 2.8) experienced increases in SJ relative peak power nearly three times more than the HHP group (1.2 ± 3.8) (Table 1). The TBJS group (3.7 ± 2.5) also experienced twice as large of an improvement in SJ height compared to the HHP group (1.7 ± 3.1) (Table 1).

Vertical Jump Characteristics

The major findings for the SJ characteristics in this study were that the HHP group's relative peak power in the SJ increased from 41.96 W/kg to 43.13 W/kg, which is a mean increase of 1.16 W/kg, while the TBJS group increased from 45.07 W/kg to 48.54 W/kg, which is a mean increase of 3.46 W/kg (Table 2). This represents a 2.7% and 7.7% increase in SJ peak power for the HHP and TBJS groups, respectively. The data also show that the HHP group improved their SJ height from 26.63 cm to 28.29 cm, which is a mean increase of 1.65 cm, while the TBJS group improved SJ height from 29.22 cm to 32.6 cm which is a mean increase of 3.35 cm (Table 2). These numbers represent an increase in SJ height of 6.2% and 11.6%, respectively. These results support the original hypothesis that there would be no significant difference between groups, but that the TBJS group may have a non-significant advantage for improving jumping performance. Although research on this topic is very limited, the results of the current study are supported by Teo et al.'s. (2016) study where there were no significant ($p > 0.05$) differences in vertical jump improvements when comparing a 6-week jump focused training program to an Olympic lifting training program.

The major findings for the CMJ characteristics in this study were that the HHP group's relative peak power in the CMJ went from 41.64 W/kg to 44.61 W/kg, which is a mean increase of 3.08 W/kg, while the TBJS group when from 42.24 W/kg to 46.59 W/kg, which is a mean increase of 4.24 W/kg (Table 3). This represents a 7.1% and 10.3% increase in CMJ peak power for the HHP and TBJS groups, respectively. The data also show that the HHP group improved their CMJ height from 25.07 cm to 28.95 cm, which is a mean increase of 3.88 cm, while the

TBJS group improved CMJ height from 27.73 cm to 31.57 cm, which is a mean increase of 3.84 cm (Table 3). These numbers represent an increase in CMJ height of 15.5% and 13.9%, respectively. These results do not support the original hypothesis as the HHP group improved their CMJ more than the TBJS group, even though it was by a non-significant ($p > 0.05$) margin. This is likely because the HHP and TBJS are similar in both movement pattern and contraction velocity to that of a vertical jump (Canavan et al., 1996; Suchomel et al., 2015). It should also be noted that the loads used in the HHP were relatively higher than the loads employed in the TBJS, therefore the HHP might have had a larger effect on the CMJ due to the athletes simply handling heavier external loads (Tricoli et al., 2005).

The findings of neither the HHP nor TBJS having any significant advantage over one another, support the original hypothesis. The TBJS group did improve more than the HHP group, by an insignificant ($p > 0.05$) margin, in the vertical jump measures, especially those in the SJ. These results also agree with the study by Teo et al. (2016) that found that there were no significant differences in any of the dependent measures between an Olympic lifting group and a vertical jump training group. In contrast, Teo et al.'s study did find non-significant increases in favor of the Olympic lifting group compared to the jump group (Teo et al., 2016). This could have been due to several factors, including the fact that the vertical jump training group did not include any weighted jump variations such as the TBJS used in the current study. Obtaining peak power is best accomplished by lifting a specific load at a specific velocity (Verkhoshansky & Siff, 2009), and the window for both is quite small as too heavy a load will result in a significant decrease in velocity, and too light of an external load is insufficient for optimal power output. Therefore it could be concluded that the un-weighted jump training in Teo et al.'s (2016) study did not have enough load to optimally train power. This is likely because un-weighted movements are too far on the velocity side of the force-velocity curve, and are therefore not specific to power or force adaptations, especially in relatively novice volunteers (Suchomel et al., 2015; Villarreal et al., 2012). The same can be said for research that has examined the effects of only plyometric, only resistance, or combined plyometric and resistance training programs. Several studies have found that the combination of resistance training and plyometrics was the most effective for improving force, power and velocity measures, likely because both sides of the force-velocity curve were being stimulated (Channell & Barfield, 2008; Fatourous et al., 2000; Harris et al., 2000). The training program completed in the current study was designed to target all aspects of the force-velocity curve as traditional strength training was implemented alongside the HHP and TBJS. Both the HHP and TBJS include rapid use of the stretch shortening cycle and are therefore considered to be plyometric in nature, whereas the strength lifts like the squat and deadlift are best suited to stimulating the force side of the curve (Suchomel et al., 2015; Verkhoshansky & Siff, 2009).

The overall insignificant difference between the HHP and TBJS groups in the current study, for both SJ and CMJ, are in agreement with much of the literature, as both the Olympic lifts and their variations, and weighted jumps have been found to increase, or at least have strong positive relationships to jump performance (Haff et al., 2005; Hori et al., 2008; Oranchuk & Jordan, 2013; Suchomel et al., 2015; Swinton et al., 2012; Thomas et al., 2015; West, Owen, Cunningham et al., 2011). These findings can likely be traced back to both specificity of contraction type and movement pattern specificity. The Olympic lifts, weighted jumps and un-weighted jumps are known to recruit a high percentage of the fast-twitch type IIA and IIX muscle fibers in order to be properly performed (Aagaard et al., 2000, Verkhoshansky & Siff, 2009). Therefore, training the Olympic lifts and/or weighted jumps would help an athlete to hypertrophy the fast-twitch muscle fibers, and activate the neuromuscular system in a manner that is specific and conducive for improving un-weighted jumping and other measures of explosive power (Channell & Barfield, 2008; Verkhoshansky & Siff, 2009). Additionally, the Olympic lifts and weighted jumps are both high velocity movements that require rapid displacement of the body and/or barbell (Suchomel et al., 2015), which has been found to be very specific to the velocity and biomechanics of an un-weighted jump (Canavan et al., 1996).

The rapid, type-II dominated, contraction type used with the Olympic lifts, weighted jumps and un-weighted jumps are very similar (Canavan et al., 1996), and although the same can be said for movement pattern specificity, it is clear that weighted jumps are more specific to un-weighted jumps compared to the Olympic lifts (Nigg et al., 2000; Oranchuk & Jordan, 2013; Swinton et al., 2012). This is especially true for the TBJS as the trap-bar allows the center of mass of the external load to remain more in-line with the body's center of mass, which allows for more favorable biomechanical leverages and transfer of force into the external load and the ground (Nigg et al., 2000; Swinton et al., 2012). This biomechanical difference between the trap-bar and the straight bar used in Olympic lifts also make the movement easier to learn, and therefore allow for heavier loads to be used sooner, resulting in greater strength and/or power gains (Gentry, Pratt & Caterisano, 1987).

Although insignificant, the larger increases in jump performance make sense due to the concept of specificity. If one wants to run fast, then the most specific and logical way to do so, is to run fast; likewise, if one wants to be strong, then the most efficient way to get stronger would be to lift heavy weights, and the same can be said for jump training. Therefore, it should come as very little surprise that the group who performed the TBJS, improved the most in the jumping measures. That being said, the Olympic lifts are also quite specific for jumping as they involve rapid extension of the hips, knees and ankles in a similar fashion to jumping (Carvalho et al., 2014; Suchomel et al., 2015). The fact that both the HHP and TBJS movements are relatively similar to each other (Canavan et al., 1996), combined with a relatively short 10-week intervention time, compared to a yearly or multi-year training plan, are the most likely reasons for no statistical difference in improvements found between groups for the vertical jumps measured.

Isometric Force-Time Characteristics

The major findings for the IMTP characteristics in this study were that the HHP group's relative peak force increased from 32.35 N/kg to 35.63 N/kg, which is a mean increase of 3.28 N/kg, while the TBJS group increased from 34.27 N/kg to 38.21 N/kg, which is a mean increase of 3.94 N/kg (Table 4). This represents a 10.1% and 11.5% increase in IMTP peak force for the HHP and TBJS groups, respectively. The data also show that the HHP group improved peak RFD from 5007 N/s to 5492 N/s, which is a mean increase of 486 N/s, while the TBJS group improved peak RFD from 4286 N/s to 4941 N/s which is a mean increase of 655 N/s (Table 4). These numbers represent an increase in peak RFD of 9.7% and 15.3% for the HHP and TBJS groups, respectively. The data shown in Table 1 indicate that there were no significant differences between groups for force produced at 50 ms, 100 ms, 150 ms, 200 ms or 250 ms.

These results support the first hypothesis that there would be no significant differences between groups for the isometric force-time characteristics. However, the secondary hypothesis that the HHP group would perform slightly better than the TBJS group was not supported, as the TBJS group increased their relative peak force and peak RFD by 11.5 and 15.3% respectively, while the HHP group improved their relative peak force and peak RFD by slightly less: 10.1 and 9.7%, respectively. This could have been due to several factors such as the fact that the isometric nature of the IMTP makes it much more specific for measuring changes towards the force end of the force-velocity curve (Suchomel & DeWeese, 2015; Suchomel, DeWeese, Beckham, Serrano & French, 2014; Suchomel, Wright, Kernozek & Kline, 2014; Verkhoshansky, 2009). The relative additional loads that can be used to train power are higher in the HHP compared to the TBJS group (Comfort et al., 2012; Turner et al., 2015). This places the HHP slightly closer to the force side of the force-velocity curve (Figure 1), compared to weighted jumps; however this is not nearly as large as the different placement on the force-velocity curve between weighted jumps and other movements such as the mid-thigh pull, or Olympic movements from the knee or floor (Figure 1). Therefore, it would make sense that neither the TBJS nor the HHP would have significant effects on isometric peak force, and that the improvements in peak force were most likely due to the traditional resistance training program that was completed following the HHP or TBJS exercises in both groups. This theory is supported in the current literature as studies by Fatourous et al. (2000) and Harris et al. (2000) both examined strength training only, plyometric only and combined training. Both studies found that although the combined training groups experienced improvements in both plyometric and strength metrics, that the strength training only, and plyometric training only groups improved significantly in strength and plyometrics, respectively (Fatourous et al., 2000; Harris et al., 2000). This relates to the current study as both the HHP and TBJS are considered to be high velocity and relatively low force exercises, and the accompanying volume-equated strength training program that all participants completed was primarily focused on increasing force outputs; therefore the two interventions were minimally different, as designed by the researcher.

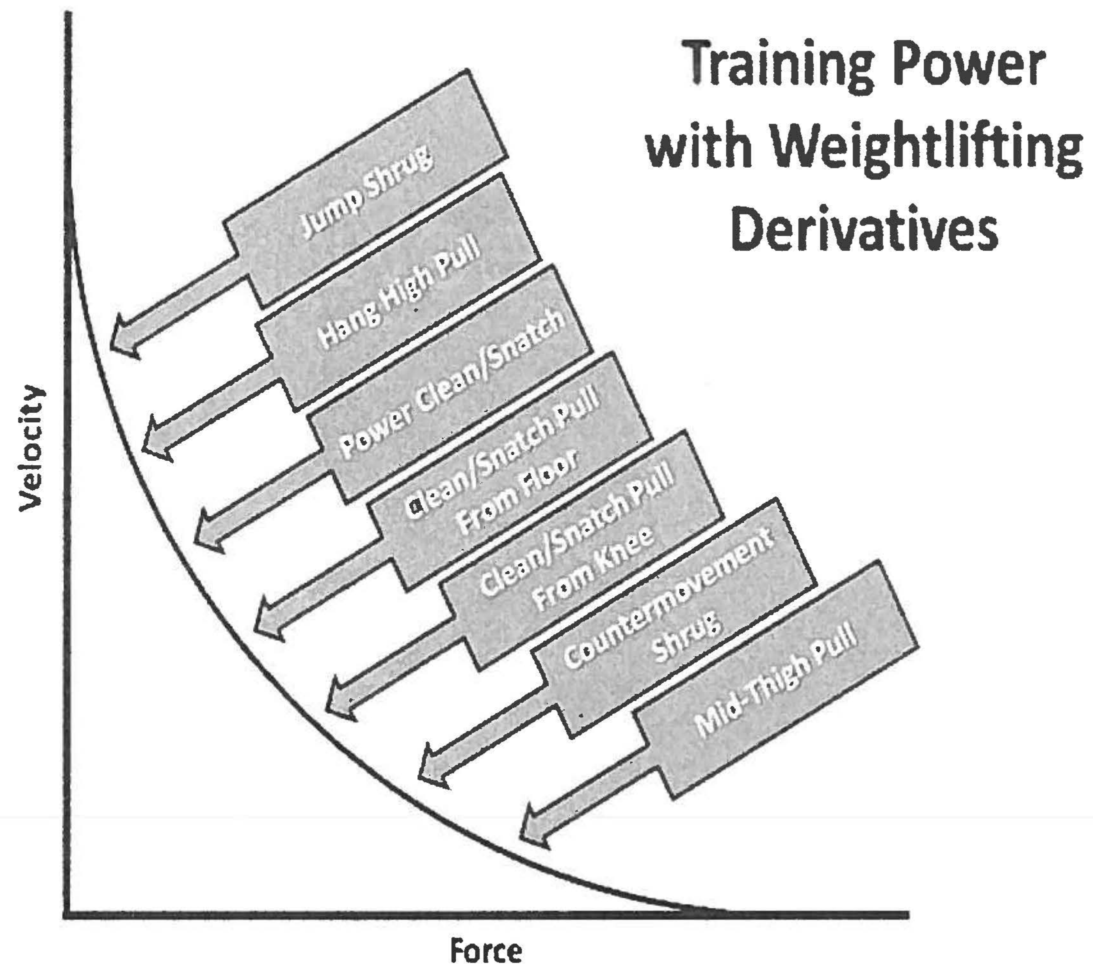

Figure 1. Force-Velocity Curve for Weightlifting Derivatives
(Suchomel & DeWeese, 2015)

Peak rate of force development improved by a greater margin in the TBJS group compared to the HHP group, which once again did not support the secondary hypothesis of this study. However, this difference was not statistically significant ($p > 0.05$). This is also supported by previous research in the field; although the HHP may be more similar to the IMTP, the TBJS is completed with higher velocities which are more relatable and specific to improving RFD (Haff et al., 2005; Haff et al., 2008, Harris et al., 2000). However, the HHP and the TBJS are similar to each other as both are high velocity movements and neither are optimal for producing high levels of force (Suchomel & DeWeese, 2015; Suchomel et al., 2015). Additionally, although isometric peak RFD is considered to be a valid means of predicting sport performance, it is not as stable or reliable as peak force or force at specific time-bands, and therefore the results may have been affected by small day to day fluctuations in motor unit recruitment patterns, motor unit synchronization or motivation (Haff et al., 2015; Wang et al., 2016). For this reason, the data for relative force at 50, 100, 150, 200 and 250 ms were all included in the current study.

As with all other measures, there was no significant between group differences for relative force at 50 ms, 100 ms, 150 ms, 200 ms or 250 ms in the IMTP. This serves as a more reliable means of quantifying changes in RFD over time and can be used alongside PRFD to support the hypothesis that neither the HHP nor the TBJS had a significant advantage for improving RFD in the current study. Knowing force at specific time-bands may serve to give coaches of specific sports insight since different sports may require larger forces at specific times (Verkhoshansky & Siff, 2009). For example, elite distance runners typically have ground contact times of approximately 160-300 ms, long jumpers tend to have ground contact times of approximately 20 ms, and elite sprinters may have ground contact times as short as 8 ms (Dietz & Peterson, 2012; Verkhoshansky & Siff, 2009). This information may be useful for designing programs that are specific to different athletes/events, and for tracking progress over time. A coach may want to focus on building RFD and force output at specific time points based on their athlete's sport or event, such as a sprinter who needs to produce a high percentage of his/her peak force within 8-10 ms (Dietz & Peterson, 2012). However the results of the current study show no significant ($p > 0.05$) differences between intervention types for any of the five time-bands. Therefore, it can be concluded that there was truly no significant difference in RFD, whether it be peak RFD or relative force at five time-bands, between the HHP and TBJS groups. This is likely due to the HHP and TBJS being very similar to each other in movement pattern specificity and contraction type/velocity (Canavan et al., 1996). This is supported by previous research as Teo et al.'s (2016) study also showed no significant differences in CMJ, SJ, drop-jump, and agility or acceleration performance between a vertical jump training group and an Olympic lifting group.

Conclusion

When examining the results of the current study, it can be concluded that there was no significant difference in the athletic power development seen by employing either the HHP or the TBJS as a primary movement throughout a 10-week intervention; both groups showed significant ($p < 0.05$) improvements in all measures taken, but neither intervention produced significantly ($p > 0.05$) superior results compared to the other. The data does trend towards the TBJS group potentially having a slight advantage in improving jumping performance due to a higher degree of movement pattern and neuromuscular specificity compared to the HHP (Suchomel & DeWeese, 2015; Suchomel et al., 2015; Verkhoshansky & Siff, 2009). Although there were significant improvements seen in the IMTP metrics in both the HHP and TBJS groups, there were no notable differences between groups, although both improved significantly ($p < 0.05$). Therefore, it can be concluded that the HHP and TBJS are nearly equal in similarity to the IMTP, and both exercises had similar input on the changes seen in isometric relative peak force and RFD metrics.

Based on the results of the current study, two primary take-away points can be highlighted. Firstly, the Olympic lifts, like the HHP, and weighted jumps, like the TBJS, can both be used to effectively train the vertical jump (Haff et al., 2005; Hori et al., 2008; Oranchuk & Jordan, 2013; Suchomel et al., 2015; Swinton et al., 2012; Thomas et al., 2015). That being said, the TBJS does seem to have practical benefits over the HHP and other Olympic lifts, as the TBJS is easier to learn and does not require the same level of expert coaching as the Olympic lifts (Swinton et al., 2011). Secondly, neither the TBJS nor the HHP should be considered specific to improving force production. In the same way as the best way to jump higher is to train jumping, and the best way to run fast is to train with some fast running, focusing on strength movements such as the squat or deadlift are likely the better tool for the job when aiming to improve force outputs (Haff et al., 2015; Wang et al., 2016).

Chapter VI

Summary and Conclusions

Summary of Major Findings

The purpose of this study was to compare the development of lower body power, force and rate of force development (RFD) in NCAA Division II swimmers using either the hang high-pull (HHP) or the trap-bar jump squat (TBJS) as their primary high velocity resistance training exercise over a ten-week intervention. Specifically, this study aimed to test whether or not the trap-bar squat jump is a more efficient and effective means of improving lower body power, force and RFD when compared to the more common hang high-pull.

To investigate this question, all participants completed a ten-week intervention focusing on either the TBJS or HHP as their primary high velocity resistance training exercise. Pre- and post-intervention, the participants performed countermovement (CMJ) and squat jumps (SJ) on force plates to measure relative peak power (W/kg) as well as jump height (cm). The participants also performed the isometric mid-thigh pull (IMTP) to measure relative peak force (N/kg), relative force (N/kg) at 50, 100, 150, 200 and 200 ms as well as peak rate of force development (PRFD). The SJ and CMJ were chosen as the vertical jump is a valid and reliable means of measuring anaerobic power in athletes and can also serve as a performance indicator in many sports (Komi, 2003; Loturco et al., 2015; McLellan et al., 2011; Nuzzo et al., 2008; Radenkovic & Stankovic, 2012; Thompson et al., 2013; Verkhoshansky & Siff, 2009; Waller et al., 2013). The IMTP was chosen as it has been found to be an extremely accurate and reliable means of measuring and tracking force and RFD over time, which have been shown to have a strong positive relationship to other strength measures (Bazyler et al., 2015; Beretic et al., 2013;

Fry et al., 1992; Haff et al., 2008; Haff et al., 2005; Haff et al., 2015; Haff et al., 1997; Kawamori et al., 2006; McGuigan et al., 2010; McGuigan & Winchester, 2008; Murphy & Wilson, 1996; Painter et al., 2011).

The researcher hypothesized that neither the trap-bar jump squat (TBJS) nor the hang high-pull (HHP) would be significantly more effective than the other for improving outputs in the countermovement jump (CMJ), squat jump (SJ) or the isometric mid-thigh pull (IMTP). It was also hypothesised that the TBJS may do a slightly better job at improving the SJ and CMJ measurements since the TBJS is more specific than the HHP to the un-weighted vertical jump in both movement pattern and contraction type specificity (Canavan et al., 1996; Oranchuk & Jordan, 2013). The researcher also hypothesised that the HHP may be superior to the TBJS for improving the isometric force-time characteristics measured since the HHP and IMTP are seemingly more specific to each other as they both involve expressing force rapidly on a barbell at approximately mid-thigh height (Haff et al., 2005; Suchomel et al., 2015). The results from this study support the main hypothesis as the data revealed no significant ($p > 0.05$) differences in any of the dependent variables between the HHP and TBJS groups. Although both groups improved by a statistically significant amount ($p < 0.05$) in all measures, none of the differences between groups were significant ($p > 0.05$). The TBJS group improved by a greater margin ($p > 0.05$) than the HHP group in every measurement except for relative force at 150 and 200 ms. Medium effect sizes were also seen in the SJ relative peak power ($r = 0.33$) and jump height ($r = 0.30$). This would suggest that there is a possibility that the larger improvement in SJ power and height for the TBJS group may not have been due purely to coincidence, and that the TBJS may in fact have a non-significant advantage over the HHP for improving jumping performance.

Recommendations for Future Research

To date, only one other research study has compared the effectiveness for improving athletic power measures between jumps and the Olympic weightlifting movements (Teo et al., 2016). Both the current study and the study by Teo and colleagues (2016) compared an intervention focusing on either jump training or weightlifting derivatives. Both studies found no significant ($p > 0.05$) difference in any of the dependent variables measured. The dependent variables in the current study were vertical jump performance and isometric force, while Teo et al.'s (2016) study examined the effect of their intervention on vertical jump, sprint and agility tests. The combination of the current study and Teo et al.'s (2016) study include a wide variety of strength (IMTP), speed (sprinting), change of direction (agility), and jumping (SJ, CMJ) tests; however, neither study specifically used strength and power athletes as subjects.

The results of the current study on competitive swimmers, and Teo et al.'s (2016) study, examining recreationally resistance trained men, can likely be applied to many different athletes. However, there is a reasonable chance that results of these studies could have differed, if tested in other sports or resistance training experience levels, as different levels of base strength can greatly affect adaptations seen from a training program (Haff & Triplett, 2015, Verkhoshansky & Siff, 2009). The swimmers in the current study were required to have at least one year of resistance training experience prior to the intervention, but one year is still a relatively short period of time compared to many elite strength and power-based athletes who may have been resistance training for several years. On the other side of the coin, all of the swimmers were between 18 and 24 years of age, and therefore were likely more developed and experienced from a resistance training and motor skill/coordination standpoint compared to most teenage, or pre-teen athletes. Performing a similar intervention on youth or novice athletes may have resulted in different results, which could logically have favored the TBJS as it is considered less complex compared to the Olympic lifts (Fees & Martin, 1997). The opposite could be assumed for advanced athletes who can perform the Olympic lifts with optimal technique, as the greater external loads that can be used in the Olympic lifts may allow for a wider range of adaptations to occur (Tricoli et al., 2005).

The current study examined the TBJS and the HHP as high velocity resistance training exercises; weighted jumps have been shown to be optimized when using the trap-bar (McKenzie et al., 2014; Swinton et al., 2012) and the HHP has been shown to be at least as effective in producing power compared to the power clean and other Olympic lifts (Comfort et al., 2011a; Suchomel et al., 2015; Suchomel, Wright, Kernozek & Kline, 2014). Although the TBJS and HHP are likely the most effective choices, there are many other weighted jump and Olympic lifting variations (McKenzie et al., 2014; Swinton et al., 2012; Suchomel & DeWeese, 2015). Weighted jumps can be performed with the barbell on the shoulders (Swinton et al., 2012), or by holding dumbbells (McKenzie et al., 2014). There are also countless Olympic lifting variations such as the power clean, clean high pull, mid-thigh pull and the jump shrug (Comfort et al, 2011a; Suchomel et al., 2015, Suchomel, DeWeese, Beckham, Serrano & French 2014; Suchomel, Wright, Kernozek & Kline, 2014), which have been shown to be effective for producing large amounts of force and power. Therefore, future studies may want to compare other types or combinations of weighted jumps and Olympic lifts.

Although 18 subjects is not necessarily a small sample size, a larger sample would have been preferable, and may have increased the potential to find statistical significance between the HHP and TBJS groups. This is especially true in the SJ relative peak power (W/kg) and jump height (cm) measurements, both of which had medium effect sizes.

Although the main reason for swimmers serving as the population for this study was for convenience, and had very little to do with the sport of swimming itself, it is clear that lower-body power and jumping performance can assist in start and turn performance (Beretic et al., 2013; Bishop et al., 2013, West, Owen, Cunningham, 2011). It may be useful to directly measure start performance in swimmers if the current study were to be repeated.

Finally, the improvements in the outcome measures between the HHP and TBJS could have been due solely to the volume equated traditional resistance training program that was completed after the HHP and TBJS, respectively. The entirety of the pre- to post-intervention changes could have had nothing to do with the HHP or TBJS, but instead could have been due to the athletes simply becoming stronger through the movements like the squat, or deadlifts. Therefore, future research may wish to include a control group, or a "traditional resistance training only" group.

Practical Applications

The results show that weighted jumps may be equally effective as Olympic weightlifting derivatives for improving certain athletic performance measures. This finding may be extremely valuable for strength and conditioning and sport coaches as well as athletes. Although the Olympic lifting movements have been engrained in the strength and conditioning culture, they require expert coaching, specialized equipment and considerable time to learn and perform properly (Fees & Martin, 1997). Strength and conditioning coaches who may have difficulty implementing the Olympic lifts, may use weighted jumps as a comparatively simpler exercise choice to coach and implement in order to train and build power (Fees & Martin, 1997). Even coaches with expert coaching skills may have difficulties implementing weightlifting derivatives in large team settings where there may be 30 or more athletes to one coach; therefore implementing weighted jumps may not only be equally effective, but also safer than the weightlifting movements (Swinton et al., 2012). The lesser learning curve is also important because many coaches are forced into a "get results now" mind set. This decreases the time available to teach complex movements and makes the less complex weighted jumps more valuable. Beyond having a less steep learning curve compared to the weightlifting movements, weighted jumps do not require special platforms or bumper plates for safe execution which potentially makes them a practical choice to a greater number of coaches, athletes and facilities (Haff & Triplett, 2015). Not only do weighted jumps require less equipment, have lower coaching demands and may be easier for the majority of athletes to learn, but the results from the current study suggest that they may be at least as effective as the Olympic lifts for improving jumping performance and force producing capabilities.

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Appendix A

Institutional Review Board Request Form

Adams State University

Request to obtain approval for the use of human participants – expedited review

Date: November 15th

To: Beth Bonnstetter, Chair ASU Institutional Review Board

Name: Dustin Oranchuk

Email: dustinoranchuk@adams.edu

Mailing Address: 511 Main Street, Apartment #1, Alamosa Colorado, USA 81101

Phone: 203-970-9654

Responsible Faculty Member: Tracey Robinson, Ph.D.

Email: tlrobins@adams.edu

Subject: Monitoring changes in maximal force production and vertical jump performance in NCAA Division II swimmers from a 10-week training program focusing on either the hang high-pull or trap-bar jump squat.

Others in Contact with Human Participants:

Research Assistants: Matt Gersick (MA, CSCS/Director of Strength & Conditioning, Adams State University), Jason Mannerberg (MS/Assistant Strength & Conditioning Coach, Adams State University), Connor Stevens (CSCS/Graduate Assistant Strength & Conditioning Coach, Adams State University), and possible HPPE undergraduate students.

Title of the Research: Comparison of the Hang High-Pull & Trap-Bar Jump Squat in the Development of Vertical Jump & Isometric Force-Time Characteristics

Objectives of the Research

Strength and power are two very important athletic qualities that can have a great impact on competitive performance. Therefore, improving strength and power are common focuses in physical preparation programs designed by coaches. One means of improving strength and power in athletes is by regularly performing the Olympic lifts and their variations such as the hang high-pull. Another means that has not been as thoroughly studied is weighted jumps, especially with the use of a trap-bar. The objective of this research study is to compare the changes seen in strength and power, as measured via vertical jumps and the isometric mid-thigh pull, via performing either the hang high-pull or the trap-bar jump squat as the primary training movement over a 10-week training period.

Methods of Procedure

Setting:

This study's pre- and post-testing and intervention will take place entirely at the Adams State University Athletic Department's weight room, located in Plachy Hall.

Participants:

A group of 11 male and 11 female collegiate swimmers from Adams State University, from 18-23 years of age will volunteer for this study. The swimmers' coach, Dan France, has given his permission for his team to participate in this study.

Procedures:

This study will require 12 weeks of participation in total and will include testing in countermovement jumps, squat jumps and isometric mid-thigh pulls, and several resistance training exercises, all of which each athlete has performed on a weekly basis for at least 6 weeks prior to the study, and is similar to their regular physical preparation.

Pre-Intervention

Prior to the pre-intervention week of data collection, the participants will fill out and sign the informed consent forms. They will also have their basic anthropometric data collected including height, weight and body composition via electronic scale, stadiometer and skinfold testing respectively. They will also fill out a short survey about their resistance training experience. Their information will be entered into an Excel spread sheet and the participants will be randomly divided into either the hang high-pull group or the trap-bar jump squat group with equal representation of both genders and training experience represented in each group.

On the first day of the week of pre-intervention testing, the athletes will arrive at the Plachy Hall weight-room and will be led through a dynamic warm-up designed to decrease injury risk and increase performance. After the warm-up, they will each perform 5 countermovement jumps and 5 squat jumps, separated by 1 minute of rest, on force plates to collect their ground reaction forces. After they complete their jumps they will be dismissed for the day.

Forty-eight hours following the first data collection day, the participants will arrive at the Plachy Hall weight-room and undergo the same warm-up as the previous session. Following the dynamic warm-ups, the participants will be given two familiarization attempts with the isometric mid-thigh pull at 50% and 75% of maximal perceived effort. After the familiarization attempts, each participant will be given 2 maximal attempts separated by 3 minutes of rest. If the 2 maximal attempts differ by greater than 500 Newtons, they will be given a 3rd attempt. After the athletes finish their isometric mid-thigh pull attempts they will be dismissed.

Forty-eight hours following the second data collection day, the participants will arrive at the Plachy Hall weight-room and complete the same warm-up as the previous sessions. The athletes in the hang-high pull will then perform a specific power clean warm-up and proceed to work up in weight in the power clean, using the standard NSCA warm-up protocol supervised by a certified strength and conditioning specialist, until they reach their 1-RM for the exercise. After the dynamic warm-up, the athletes in the trap-bar jump squat group will begin a specific warm-up for the trap-bar deadlift and under the supervision and spotting of a CSCS, and using the standard NSCA warm-up protocol, they will find their 1-RM for the exercise. After the athletes find the 1-RM for their respective exercise, the researchers will calculate specific percentages of the 1-RM power clean and box squat to find the loads that each individual athlete will use for the hang high-pull or trap-bar jump squat throughout the intervention period. All loads will be based off of existing peer-reviewed research.

Intervention:

Beginning the week following the pre-intervention testing, and for 8 weeks, all of the participants will train under the supervision and instruction of a CSCS. The participants will perform their respective high velocity resistance training movement (hang high-pull or trap-bar jump squat) twice/week using set and rep ranges that have been shown in previous research to be safe and effective in improving strength and power. After the completion of the high velocity resistance training movements, the participants will complete their regular resistance training program. All technique will be closely monitored by the CSCS and research assistants throughout the interventions (Appendix C).

Post Intervention:

After the conclusion of the 10-week intervention period, the athletes will be given 4 days of rest. After the 4-day rest period, the participants will return to Plachy Hall and once again have their basic anthropometric data collected. They will then undergo a dynamic warm-up before completing 5 countermovement and 5 squat jumps on force-plates with 1 minute of rest between jumps.

Forty-eight hours later, they will return to the weight-room and undergo the same dynamic warm-up and testing procedure from the pre-intervention testing for the isometric mid-thigh pull.

Once they complete the post-testing, no further participation will be required.

Research Design:

Data will be analysed using SPSS statistical analysis software. The independent variable in this study will be the treatment groups (Hang high-pull or trap-bar jump squat). The dependent variables will be vertical jump height (cm), takeoff velocity (m/s) and net positive impulse in the countermovement and squat jumps. and peak force (N), relative peak force (N/kg) and rate of force development (N/s) in the isometric mid-thigh pull.

Protection Measures

Participation is voluntary and will be held confidential. Participants may choose not to answer any question they do not want to answer and/or may withdraw from participation at any time without penalty. Names will not be used in the study; participants will be assigned a number and only group data will be reported. Data will be locked under a password protected computer for five years in which only the primary researcher will have the password. Adams State University reserves the right to use the results of this study for future research and/or presentations. In such cases, participants will be asked to sign a release form freeing all collected information prior to its use by the institution or researcher. If the research is used in a public forum, data will be reported as a group without individual identification.

Consent: Participants will be asked to read over and sign the consent form before any testing begins. The informed consent is attached separately.

Changes: If any changes are made to the research, I will contact the IRB immediately and fill out the needed paperwork.

Brian Zuleger ______ 2-23-16

Name and Signature of Department Chair or Appropriate Person Date

______ 3-4-17

Name and Signature of IRB chair Date

3-4-16
3-4-17

Appendix B

Informed Consent for Resistance Training Intervention Research Study

Comparison of the Hang High-Pull & Trap-Bar Jump Squat in the Development of Vertical Jump & Isometric Force-Time Characteristics

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Purpose of Research

The purpose of the research is to compare the development of lower body power, force and rate of force development in NCAA Division II swimmers using either the hang high-pull or the trap-bar jump squat as their primary high velocity resistance training exercise. As a NCAA Division II swimmer for Adams State University, you have met the criteria to be a potential volunteer for this study.

Procedures

Pre-Post intervention data collection:

One week before the intervention begins, participants will have basic anthropometric data collected, including height, weight and body composition with skinfolds. They will then be randomly divided into two groups of equal genders, age and resistance training experience.

Group 1 will perform the hang high-pull as their primary high velocity resistance training movement for the 10-week intervention. Group 2 will perform the trap-bar jump squat as their primary high velocity resistance training movement for the 10-week intervention.

On the Monday preceding the intervention, all participants will perform a dynamic warm-up followed by collecting baseline data in the countermovement jump and squat jump with the use of force plates.

On the Wednesday preceding the intervention, all participants will perform a dynamic warm-up followed by collecting baseline data in the isometric midthigh pull.

On the Friday preceding the intervention, group 1 will test their 1 repetition maximum for the power clean, and percentages based on previous research will be calculated to determine their training loads for the hang high-pull for the duration of the intervention.

On the Friday preceding the intervention, group 2 will test their 1 repetition maximum for the trap-bar deadlift. Percentages based on previous research will be calculated to determine their training loads of the trap-bar jump squat for the duration of the intervention.

The week following the 10-week intervention, the participants will complete post-testing which will follow the same order as the pre-testing that occurred during the week prior to the intervention.

Training Program:

The program must be followed strictly as outlined for the full 10 weeks. This program is based on strong empirical evidence and will be targeting strength and power specific to the vital aspects of both explosive strength/power and swimming specific movements.

The 10-week training program will be performed in the Plachy Hall weight room, under the supervision of the primary researcher Dustin Oranchuk (BKin, CSCS, ISAK/ HPPE Graduate Assistant, Assistant Strength & Conditioning Coach, Adams State University), and the research assistants, Matt Gersick (MA, CSCS/Director of Strength & Conditioning, Adams State University), Jason Mannerberg (MS/Assistant Strength & Conditioning Coach, Adams State University) and Connor Stevens (BS, CSCS/Graduate Assistant Strength & Conditioning Coach).

If you are randomly selected to participate in the hang high-pull group, you will perform the hang high-pull twice/week (Monday, Friday), followed by your regular resistance training program.

If you are randomly selected to participate in the trap-bar jump squat group, you will perform the hang trap-bar jump squat twice/week (Monday, Friday), followed by your regular resistance training program.

Specific Laboratory Tests Include:

1. You will be asked to fill out a short survey asking about your resistance training experiences.
2. You will have your basic anthropometric information collected (weight, height, body composition) in the Human Performance Lab at Adams State University.
3. You will perform 5 maximal effort countermovement and squat jumps using force plates in the Plachy Hall weight-room at Adams State University.
4. You will perform 2 maximal effort isometric mid-thigh pulls on force plates in the Plachy Hall weight-room at Adams State University.

Duration of Participation

12 weeks

Benefits to the Individual

Participants will receive instruction, individual attention and a training program specifically designed to aid them in their athletic goals. The training program for both groups are based on empirical evidence and targets variables known to be responsible for significant increases in strength and power, and therefore increased athletic performance.

Risks to the Individual

Risk in this study is minimal due to all training and testing being completed is nearly identical to the normal training and physical preparation that would typically be performed. Additionally, all subjects have received instruction in all of the training and testing exercises that will be used during this study. Participants will also be under close supervision of the primary researcher and research assistants, all of whom are Certified Strength & Conditioning Specialists, certified by the NSCA. However, all exercises regardless of measures taken have some risk for injury. This program may also cause muscular discomfort and/or soreness that is associated with resistance training that targets strength and power.

Confidentiality/Use of Records

All information that is obtained during the study will be treated as privileged and confidential. All information will be secured in a locked drawer only accessible by the primary researcher. The information obtained, however, may be used for statistical analysis or scientific purposes with your right to privacy retained. The data, without the names of the participants, and you privacy retained, may be published in a peer-reviewed research journal and/or may be presented at an academic conference in a poster and/or oral presentation as group data only.

Contact Information

Primary Investigator	Thesis Advisor	Committee Member
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"I understand that I can withdraw my participation at any time and will not suffer a penalty for doing so."

"I HAVE HAD THE OPPORTUNITY TO READ THIS CONSENT FORM, ASK QUESTIONS ABOUT THE RESEARCH PROJECT AND AM PREPARED TO PARTICIPATE IN THIS PROJECT."

______________________________________ ______________________

Participant's Signature Date

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Participant's Printed Name

______________________________________ ______________________

Researcher's Signature Date

Appendix C

Full Weight-Room Training Program for 10-Week Macrocycle

Table 5: ASU Swimming Resistance Training Program: Accumulation Mesocycle

Monday	Week 1	Week 2
Exercise	Sets X Reps @ Load / Rest	Sets x Reps @ Load / Rest
A: Hang High-Pull	4 X 4 @ 75%* / 90s	5 X 5 @ 75% / 90s
Or		
A: Trap-Bar Jump Squat	4 X 4 @ 20%** / 90s	5 X 5 @ 20% / 90s
B1: Back Squat	4 X 5-6 @ 75% / 30s	4 X 6-7 @ 75% / 30s
B2: Pronated Pull-Downs	4 X 8-10 / 30s	4 X 8-10 / 30s
B3: Mini-band Lateral Shuffle	3 X 20 / 60s	3 X 20 / 60s
C1: Banded Push-up	4 X Max reps / 30s	4 X Max reps / 30s
C2: Back Extension + DB Row	4 X 10-12 / 30s	4 X 10-12 / 30s
C3: DB Powell Raise	3 X 8-12 / 30s	3 X 8-12 / 30s

Wednesday	Week 1	Week 2
Exercise	Sets X Reps @ Load / Rest	Sets X Reps @ Load / Rest
A: Seated MB Jumps	3 X 4 / 60s	3 X 6 / 60s
B1: DB Reverse Drop Lunge	4 X 6-8 / 30s	4 X 6-8 / 30s
B2: Supine MB Throw	4 X 6-8 / 30s	4 X 6-8 / 30s
B3: MB Slams	4 X 8-10 / 30s	4 X 8-10 / 30s
C1: Side-Plank + Cable Row	3 X 15 / 30s	3 X 15 / 30s
C2: Hanging Leg Raise	3 X 20 / 30s	3 X 20 / 30s
C3: Band Pull Apart	3 X 30 / 30s	3 X 30 / 30s

Friday	Week 1	Week 2
Exercise	**Sets X Reps @ Load / Rest**	**Sets X Reps @ Load / Rest**
A: Hang High-Pull	4 X 2+2 @ 80% / 90s	5 X 2+2 @ 80% / 90s
Or		
A: Trap-Bar Jump Squat	4 X 2+2 @ 25% / 90s	5 X 2+2 @ 25% / 90s
B1: Trap-Bar Deadlift	4 X 5-6 @ 75% / 30s	4 X 6-7 @ 75% / 30s
B2: Chest Supported DB Row	4 X 8-10 / 30s	4 X 8-10 / 30s
B3: Band TKE	3 X 20 / 60s	3 X 20 / 60s
C1: 1-Arm DB Incline Press	4 X 6-8 / 30s	4 X 6-8 / 30s
C2: GHR	4 X 10-12 / 30s	4 X 10-12 / 30s
C3: DB External Rotation	3 X 8-12 / 30s	3 X 8-12 / 30s

Monday	Week 3	Week 4
Exercise	**Sets X Reps @ Load / Rest**	**Sets X Reps @ Load / Rest**
A: Hang High-Pull	6 X 5 @ 75% / 90s	3 X 5 @ 80% / 90s
Or		
A: Trap-Bar Jump Squat	6 X 5 @ 20% / 90s	3 X 5 @ 25% / 90s
B1: Back Squat	4 X 7-8 @ 70% / 30s	3 X 6-8 @ 75% / 30s
B2: Pronated Pull-Downs	4 X 8-10 / 30s	3 X 8-10 / 30s
B3: Mini-band Lateral Shuffle	3 X 20 / 60s	2 X 20 / 60s
C1: Banded Push-up	4 X Max reps / 30s	2 X Max reps / 30s
C2: Back Extension+Row	4 X 10-12 / 30s	2 X 8-10 / 30s
C3: DB Powell Raise	3 X 8-12 / 30s	2 X 8-12 / 30s

Wednesday	Week 3	Week 4
Exercise	**Sets X Reps @ Load / Rest**	**Sets X Reps @ Load / Rest**
A: Seated MB Jumps	3 X 8 / 60s	3 X 5 / 60s
B1: DB Reverse Drop Lunge	4 X 6-8 / 30s	3 X 6-8 / 30s
B2: Supine MB Throw	4 X 6-8 / 30s	3 X 6-8 / 30s
B3: MB Slams	4 X 8-10 / 30s	3 X 8-10 / 30s
C1: Side-Plank + Cable Row	3 X 15 / 30s	2 X 15 / 30s
C2: Hanging Leg Raise	3 X 20 / 30s	2 X 20 / 30s
C3: Band Pull Apart	3 X 30 / 30s	2 X 30 / 30s

Friday	Week 3	Week 4
Exercise	**Sets X Reps @ Load / Rest**	**Sets X Reps @ Load / Rest**
A: Hang High-Pull	6 X 2+2+1 @ 85% / 90s	3 X 2+2 @ 85% / 90s
Or		
A: Trap-Bar Jump Squat	6 X 2+2+1 @ 30% / 90s	3 X 2+2 @ 30% / 90s
B1: Trap-Bar Deadlift	4 X 7-8 @ 70% / 30s	3 X 6-8 @ 75% / 30s
B2: Chest Supported DB Row	4 X 8-10 / 30s	3 X 8-10 / 30s
B3: Band TKE	3 X 20 / 60s	2 X 20 / 60s
C1: 1-Arm DB Incline Press	4 X 6-8 / 30s	2 X 6-8 / 30s
C2: GHR	4 X 10-12 / 30s	2 X 10-12 / 30s
C3: DB External Rotation	3 X 8-12 / 30s	2 X 8-12 / 30s

Table 6: ASU Swimming Resistance Training Program: Transmutation Mesocycle

Monday	Week 5	Week 6
Exercise	**Sets X Reps @ Load / Rest**	**Sets X Reps @ Load / Rest**
A: Hang High-Pull	5 X 5 @ 80% / 120s	6 X 4 @ 85% / 120s
Or		
A: Trap-Bar Jump Squat	5 X 5 @ 25% / 120s	6 X 4 @ 30% / 120s
B1: Back Squat	4 X 5-6 @ 80% / 60s	5 X 5-6 @ 85% / 30s
B2: Neutral Pull-Ups	4 X 5-6 / 90s	5 X 5-6 / 90s
C1: Incline DB Press	4 X 4-6 / 60s	4 X 4-6 / 60s
C2: DB Romanian Deadlift	4 X 6-8 60s	4 X 6-8 60s

Wednesday	Week 5	Week 6
Exercise	**Sets X Reps @ Load / Rest**	**Sets X Reps @ Load / Rest**
A1: MB Side Throw	3 X 5 / 30s	4 X 4 / 30s
A2: Band Pull Apart	3 X 30 / 60s	3 X 30 / 60s
B1: DB Walking Lunge	4 X 5-6 / 30s	4 X 5-6 / 30s
B2: Plyo Push-up	4 X 5 / 30s	4 X 5 / 30s
B3: Supine Partner Leg Throw	3 X 15 / 60s	3 X 15 / 60s
C1: Windshield Wipers	3 X 20 / 30s	3 X 20 / 30s
C2: KB Swing	3 X 8-10 / 30s	3 X 8-10 / 30s
C3: Internal Rotation Stretch	3 X 20-30s / 30s	3 X 20-30s / 30s

Friday	Week 5	Week 6
Exercise	**Sets X Reps @ Load / Rest**	**Sets X Reps @ Load / Rest**
A: Hang High-Pull	4 X 2+2 @ 85% / 120s	5 X 2+1 @ 90% / 120s
Or		
A: Trap-Bar Jump Squat	4 X 2+2 @ 30% / 120s	5 X 2+1 @ 35% / 120s

B1: Trap-Bar Deadlift	**4 X 4-5 @ 80% / 60s**	**5 X 4-5 @ 85% / 60s**
B2: 1 Arm DB Row	**4 X 5-6 / 90s**	**5 X 5-6 / 90s**
C1: BB Push Press	**4 X 4-5 / 60s**	**4 X 4-5 / 60s**
C2: Band Back Extension	**4 X 10-12 / 60s**	**4 X 10-12 / 60s**

Monday	**Week 7**	**Week 8**
Exercise	**Sets X Reps @ Load / Rest**	**Sets X Reps @ Load / Rest**
A: Hang High-Pull	**6 X 3 @ 87.5% / 120s**	**4 X 3 @ 90% / 120s**
Or		
A: Trap-Bar Jump Squat	**6 X 3 @ 32.5% / 120s**	**4 X 3 @ 35% / 120s**
B1: Back Squat	**5 X 3-4 @ 87.5% / 60s**	**3 X 3-4 @ 90% / 60s**
B2: Neutral Pull-Ups	**5 X 3-4 / 90s**	**3 X 3-4 / 90s**
C1: Incline DB Press	**4 X 3-4 / 60s**	**2 X 3-4 / 60s**
C2: DB Romanian Deadlift	**4 X 4-6 60s**	**2 X 4-6 60s**

Wednesday	**Week 7**	**Week 8**
Exercise	**Sets X Reps @ Load / Rest**	**Sets x Reps @ Load / Rest**
A1: MB Side Toss	**5 X 5 / 30s**	**3 X 5 / 30s**
A2: Band Pull Apart	**4 X 30 / 60s**	**2 X 30 / 60s**
B1: DB Walking Lunge	**4 X 5-6 / 30s**	**3 X 5-6 / 30s**
B2: Plyo Push-up	**4 X 5 / 30s**	**3 X 5 / 30s**
B3: Supine Partner Leg Throw	**3 X 15 / 60s**	**2 X 20 / 60s**
C1: Windshield Wipers	**3 X 20 / 30s**	**2 X 25 / 30s**
C2: KB Swing	**3 X 8-10 / 30s**	**2 X 10-12 / 30s**
C3: Internal Rotation Stretch	**3 X 20-30s / 30s**	**2 X 20-30s / 30s**

Friday	Week 7	Week 8
Exercise	**Sets X Reps @ Load / Rest**	**Sets x Reps @ Load / Rest**
A: Hang High-Pull	**6 X 1+1 @ 92.5% / 120s**	**4 X 1+1 @ 95% / 120s**
Or		
A: Trap-Bar Jump Squat	**6 X 1+1 @ 37.5% / 120s**	**4 X 1+1 @ 40% / 120s**
B1: Trap-Bar Deadlift	**5 X 3-4 @ 87.5% / 60s**	**3 X 2-3 @ 90% / 60s**
B2: 1 Arm DB Row	**5 X 4-5 / 90s**	**3 X 4-5 / 90s**
C1: BB Push Press	**4 X 3-4 / 60s**	**2 X 3-4 / 60s**
C2: Band Back Extension	**4 X 10-12 / 60s**	**2 X 10-12 / 60s**

Table 7: ASU Swimming Resistance Training Program: Realization Mesocycle

Monday	Week 9	Week 10
Exercise	Sets X Reps @ Load / Rest	Sets X Reps @ Load / Rest
A: Hang High-Pull	4 X 4 @ 80% / 90s	3 X 3 @ 75% / 90s
Or		
A: Trap-Bar Jump Squat	4 X 4 @ 25% / 90s	3 X 3 @ 30% / 90s
B1: Back Squat	3 X 5-6 @ 80% / 60s	3 X 5-6 @ 70% / 60s
B2: Face-Pull	3 X 10-12 / 60s	3 X 10-12 / 60s
C1: Incline DB Press	3 X 4-6 / 45s	3 X 4-6 / 45s
C2: Single Leg Hip-Thrust	3 X 10-12 45s	3 X 10-12 45s

Thursday	Week 9	Week 10
Exercise	Sets X Reps @ Load / Rest	Sets X Reps @ Load / Rest
A: Hang High-Pull	4 X 3+2 @ 80% / 90s	2 X 1+1+1 @ 75% / 120s
Or		
A: Trap-Bar Jump Squat	4 X 3+2 @ 25% / 90s	2 X 1+1+1 @ 20% / 90s
B1: Trap-Bar Deadlift	3 X 4-5 @ 80% / 60s	2 X 4-5 @ 70% / 60s
B2: Chest Supported Row	3 X 5-6 / 30s / 60s	2 X 5-6 / 60s
C1: MB Caber Toss	3 X 4-5 / 45s	2 X 4-5 / 45s
C2: Reverse Hyper	3 X 10-12 / 45s	2 X 10-12 / 45s

***Hang High-Pull Load Percentages are based off of 1-RM power clean from beginning of study.**

****Trap-Bar Jump Squat Percentages are based off of 1-RM trap-bar deadlift from beginning of study.**

*****Back Squat Percentages are based off of 1-RM squat prior to study.**

*****Lifts without a specific Percentage are to be executed with loads as heavy as possible with good technique for the rep range stated.**

Appendix D

Table 8. Dynamic Warm-up, to be completed prior to each training/testing session

A1: High Knee Skips 2 x 10 meters	B: Base Rotations 2 x 6 seconds*
A2: Butt Kick Runs 2 x 10 meters	C: Side to Side over Line 2 x 6 seconds*
A3: Side Shuffle + Arm Swing 2 x 10 meters	D: 2-inch Runs 2 x 6 seconds*
A4: Forward Lunge + Reach 2 x 10 meters	E: Vertical Jump 2 x 6
A5: Alternating Side Lunge 2 x 10 meters	
A6: Push-Up 2 x 10	
A7: I, Y, T, W 2 x 20 each	
A8: 3-Way Band Pull-Apart 2 x 10 each	
A9: Mini-Band Lateral Shuffle 2 x 10 meters	
A10: Band TKE 2 x 20 each	
Rest 15 seconds between exercises	Rest 30 seconds between exercises

*From "EXOS Knowledge" (http://www.coreperformance.com/knowledge/workouts/the-fastest-workout-known-to-man.html)

(Oranchuk, Switaj & Zuleger, 2015)

Appendix E

Time Line for 12-Week Study

Week 1: Pre-Testing

Monday

Volunteers arrive at Plachy Hall weight-room.

Volunteers fill out and sign consent forms.

Collect anthropometric data (height, weight, skinfolds).

Use Excel spreadsheet to randomize participants into 2 groups with equal genders and events.

Volunteers are lead through a dynamic warm-up (Appendix D).

Volunteers perform 5 SJs and 5 CMJs in random order on force plates while wearing an accelerometer with 1 minute of rest between jumps.

Volunteers leave Plachy Hall.

Wednesday

Volunteers arrive at Plachy Hall weight-room.

Volunteers are lead through dynamic warm-up (Appendix D).

Volunteers perform 2 practice IMTP at 50% and 75% of maximal effort. Volunteers are given 3 minutes rest between practice pulls before the first 100% effort IMTP. Volunteers are given 3 minutes of rest between full effort IMTPs. If the first two IMTPs differ by more than 250N, a third IMTP will be performed.

Volunteers leave Plachy Hall.

Friday

Volunteers arrive at Plachy Hall weight-room.

All Volunteers are led through a dynamic warm-up (Appendix D).

Volunteers placed in the HHP group will warm-up and work up to a 1-RM in the power clean.

Volunteers placed in the TBJS group will warm-up and work up to a 1-RM in the TBDL.

Volunteers leave Plachy Hall.

Percentages of each volunteer's 1-RM in their respective lift are calculated to determine the loading for the intervention.

Weeks 2-11

Volunteers will arrive at Plachy Hall three days/week.

Monday and Friday the volunteers will perform either the HHP or TBJS at the load determined by the primary researcher (Appendix C).

After the HHP or TBJS are completed, the volunteers will proceed to perform the same resistance training program as each other (Appendix C).

Volunteers leave Plachy Hall.

Week 12: Post-Testing

Monday

Volunteers arrive at Plachy Hall weight-room

Collect anthropometric data (height, weight, skinfolds).

Volunteers are lead through a dynamic warm-up (Appendix D).

Volunteers perform 5 SJs and 5 CMJs in random order on force plates while wearing an accelerometer with 1 minute of rest between jumps.

Volunteers leave Plachy Hall.

Wednesday

Volunteers arrive at Plachy Hall weight-room.

Volunteers are lead through a dynamic warm-up (Appendix D).

Volunteers perform 2 practice IMTP at 50% and 75% of maximal effort. Volunteers are given 3 minutes rest between practice pulls before the first 100% effort IMTP. Volunteers are given 3 minutes of rest between full effort IMTPs. If the first two IMTPs differ by more than 250N, a third IMTP will be performed.

Volunteers leave Plachy Hall.

End of intervention and data collection period.

Appendix F

SPSS Outputs

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
SJPrePeakP	18	29.34	59.34	43.5183	8.63501
SJPostPeakP	18	31.27	61.32	45.8333	9.35849
SJPreJH	18	14.80	41.90	27.9278	8.09901
SJPostJH	18	17.60	44.00	30.4444	8.87543
CMJPrePeakP	18	29.38	54.24	41.9389	9.14653
CMJPostPeakP	18	32.88	61.65	45.6017	9.36374
CMJPreJH	18	15.00	42.80	26.4000	7.97496
CMJPostJH	18	16.80	48.00	30.2611	8.90394
PreForceNorm	18	23.76	47.16	33.3044	5.72660
PostForceNorm	18	26.14	46.47	36.9200	5.44687
PrePRFD	18	1972.00	7272.00	4646.2778	1481.94617
PostPRFD	18	2134.00	7775.00	5216.5000	1612.60645
Pre50ms	18	21.15	41.05	29.1572	4.73037
Post50ms	18	22.08	39.89	31.5933	4.69397
Pre100ms	18	21.53	42.49	29.9017	4.87914
Post100ms	18	23.73	41.45	32.4156	4.74948
Pre150ms	18	21.67	43.03	30.3672	4.89953
Post150ms	18	23.56	41.84	33.5083	4.99547
Pre200ms	18	21.86	43.42	30.5183	5.18359
Post200ms	18	24.05	43.41	34.0833	5.15719
Pre250ms	18	22.08	43.83	31.0250	4.95807
Post250ms	18	25.52	43.29	34.3017	5.00958
Valid N (listwise)	18				

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
SJPeakP_diff	18	-4.35	9.39	2.3150	3.46147
SJJH_diff	18	-3.30	9.70	2.5167	3.07901
CMJPeakP_diff	18	-2.66	15.53	3.6628	4.61574
CMJJH_diff	18	-2.00	8.10	3.8611	2.48386
PeakForce_diff	18	-3.90	7.76	3.6156	2.96044
RFD_diff	18	-674.00	1734.00	570.2222	595.18436

F50_diff	18	-1.16	6.10	2.4361	2.04419
F100_diff	18	-1.04	6.68	2.5139	2.14423
F150_diff	18	-1.19	6.78	3.1411	2.21705
F200_diff	18	-.30	7.62	3.5650	2.28129
F250_diff	18	-.54	7.18	3.2767	2.45136
Valid N (listwise)	18				

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
SJPrePeakP	HHP	9	41.9611	9.56365	3.18788
	TBJS	9	45.0756	7.84395	2.61465
SJPostPeakP	HHP	9	43.1289	10.66175	3.55392
	TBJS	9	48.5378	7.48203	2.49401
SJPreJH	HHP	9	26.6333	9.41023	3.13674
	TBJS	9	29.2222	6.86035	2.28678
SJPostJH	HHP	9	28.2889	10.59522	3.53174
	TBJS	9	32.6000	6.68431	2.22810
CMJPrePeakP	HHP	9	41.6389	10.09699	3.36566
	TBJS	9	42.2389	8.69619	2.89873
CMJPostPeakP	HHP	9	44.6100	10.29673	3.43224
	TBJS	9	46.5933	8.83652	2.94551
CMJPreJH	HHP	9	25.0667	8.64104	2.88035
	TBJS	9	27.7333	7.51548	2.50516
CMJPostJH	HHP	9	28.9444	9.81709	3.27236
	TBJS	9	31.5778	8.25799	2.75266
PreForceNorm	HHP	9	32.3478	5.49079	1.83026
	TBJS	9	34.2611	6.12201	2.04067
PostForceNorm	HHP	9	35.6333	5.35416	1.78472
	TBJS	9	38.2067	5.53656	1.84552
PrePRFD	HHP	9	5006.8889	1300.72023	433.57341
	TBJS	9	4285.6667	1637.79898	545.93299
PostPRFD	HHP	9	5492.2222	1427.90456	475.96819
	TBJS	9	4940.7778	1821.01591	607.00530
Pre50ms	HHP	9	28.0322	4.15216	1.38405
	TBJS	9	30.2822	5.24039	1.74680
Post50ms	HHP	9	30.2544	4.23245	1.41082
	TBJS	9	32.9322	4.98737	1.66246

Pre100ms	HHP	9	28.8833	4.34095	1.44698
	TBJS	9	30.9200	5.42317	1.80772
Post100ms	HHP	9	30.9456	4.45812	1.48604
	TBJS	9	33.8856	4.81643	1.60548
Pre150ms	HHP	9	29.2167	4.44450	1.48150
	TBJS	9	31.5178	5.31784	1.77261
Post150ms	HHP	9	32.5633	5.00717	1.66906
	TBJS	9	34.4533	5.09390	1.69797
Pre200ms	HHP	9	29.3056	4.60951	1.53650
	TBJS	9	31.7311	5.70447	1.90149
Post200ms	HHP	9	32.7167	4.93939	1.64646
	TBJS	9	35.4500	5.28371	1.76124
Pre250ms	HHP	9	30.0011	4.39299	1.46433
	TBJS	9	32.0489	5.52997	1.84332
Post250ms	HHP	9	32.8033	4.81475	1.60492
	TBJS	9	35.8000	5.00955	1.66985

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
SJPrePeakP	Equal variances assumed	1.324	.267	-.755	16	.461	-3.11444	4.12298	-11.85478	5.62589
	Equal variances not assumed			-.755	15.410	.461	-3.11444	4.12298	-11.88206	5.65317
SJPostPeakP	Equal variances assumed	3.986	.063	-1.246	16	.231	-5.40889	4.34171	-14.61290	3.79512
	Equal variances not assumed			-1.246	14.342	.233	-5.40889	4.34171	-14.70016	3.88238
SJPreJH	Equal variances assumed	1.349	.262	-.667	16	.514	-2.58889	3.88182	-10.81799	5.64021

	Equal variances not assumed			-.667	14.631	.515	-2.58889	3.88182	-10.88102	5.70325
SJPostJH	Equal variances assumed	7.105	.017	-1.032	16	.317	-4.31111	4.17584	-13.16349	4.54127
	Equal variances not assumed			-1.032	13.497	.320	-4.31111	4.17584	-13.29879	4.67657
CMJPrePeakP	Equal variances assumed	.952	.344	-.135	16	.894	-.60000	4.44188	-10.01637	8.81637
	Equal variances not assumed			-.135	15.656	.894	-.60000	4.44188	-10.03322	8.83322
CMJPostPeakP	Equal variances assumed	1.238	.282	-.439	16	.667	-1.98333	4.52286	-11.57137	7.60471
	Equal variances not assumed			-.439	15.640	.667	-1.98333	4.52286	-11.58935	7.62268
CMJPreJH	Equal variances assumed	.814	.380	-.699	16	.495	-2.66667	3.81736	-10.75910	5.42577
	Equal variances not assumed			-.699	15.698	.495	-2.66667	3.81736	-10.77177	5.43843
CMJPostJH	Equal variances assumed	1.140	.301	-.616	16	.547	-2.63333	4.27616	-11.69838	6.43172
	Equal variances not assumed			-.616	15.544	.547	-2.63333	4.27616	-11.72003	6.45337
PreForceNorm	Equal variances assumed	.042	.840	-.698	16	.495	-1.91333	2.74120	-7.72443	3.89776
	Equal variances not assumed			-.698	15.814	.495	-1.91333	2.74120	-7.72998	3.90331
PostForceNorm	Equal variances assumed	.072	.792	-1.002	16	.331	-2.57333	2.56733	-8.01582	2.86916
	Equal variances not assumed			-1.002	15.982	.331	-2.57333	2.56733	-8.01632	2.86965
PrePRFD	Equal variances assumed	.209	.654	1.035	16	.316	721.22222	697.15761	-756.68589	2199.13034
	Equal variances not assumed			1.035	15.220	.317	721.22222	697.15761	-762.86878	2205.31322
PostPRFD	Equal variances assumed	.231	.637	.715	16	.485	551.44444	771.36318	-1083.77245	2186.66134

	Equal variances not assumed			.715	15.139	.486	551.44444	771.36318	-1091.36490	2194.25379
Pre50ms	Equal variances assumed	.001	.980	-1.010	16	.328	-2.25000	2.22866	-6.97454	2.47454
	Equal variances not assumed			-1.010	15.205	.328	-2.25000	2.22866	-6.99469	2.49469
Post50ms	Equal variances assumed	.048	.830	-1.228	16	.237	-2.67778	2.18041	-7.30003	1.94447
	Equal variances not assumed			-1.228	15.588	.238	-2.67778	2.18041	-7.30999	1.95444
Pre100ms	Equal variances assumed	.009	.925	-.880	16	.392	-2.03667	2.31552	-6.94534	2.87201
	Equal variances not assumed			-.880	15.268	.393	-2.03667	2.31552	-6.96454	2.89121
Post100ms	Equal variances assumed	.012	.915	-1.344	16	.198	-2.94000	2.18766	-7.57764	1.69764
	Equal variances not assumed			-1.344	15.905	.198	-2.94000	2.18766	-7.57988	1.69988
Pre150ms	Equal variances assumed	.040	.845	-.996	16	.334	-2.30111	2.31019	-7.19851	2.59628
	Equal variances not assumed			-.996	15.511	.335	-2.30111	2.31019	-7.21108	2.60885
Post150ms	Equal variances assumed	.022	.885	-.794	16	.439	-1.89000	2.38093	-6.93735	3.15735
	Equal variances not assumed			-.794	15.995	.439	-1.89000	2.38093	-6.93747	3.15747
Pre200ms	Equal variances assumed	.001	.971	-.992	16	.336	-2.42556	2.44469	-7.60807	2.75696
	Equal variances not assumed			-.992	15.324	.337	-2.42556	2.44469	-7.62670	2.77559
Post200ms	Equal variances assumed	.010	.922	-1.134	16	.274	-2.73333	2.41098	-7.84437	2.37771
	Equal variances not assumed			-1.134	15.928	.274	-2.73333	2.41098	-7.84625	2.37959
Pre250ms	Equal variances assumed	.002	.969	-.870	16	.397	-2.04778	2.35417	-7.03839	2.94283
	Equal variances not assumed			-.870	15.221	.398	-2.04778	2.35417	-7.05922	2.96367

Post250ms	Equal variances assumed	.007	.933	-1.294	16	.214	-2.99667	2.31607	-7.90651	1.91317
	Equal variances not assumed			-1.294	15.975	.214	-2.99667	2.31607	-7.90713	1.91380

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
SJPeakP_diff	HHP	9	1.1678	3.81340	1.27113
	TBJS	9	3.4622	2.82099	.94033
SJJH_diff	HHP	9	1.6556	3.09197	1.03066
	TBJS	9	3.3778	2.98613	.99538
CMJPeakP_diff	HHP	9	3.0822	2.33339	.77780
	TBJS	9	4.2433	6.25061	2.08354
CMJJH_diff	HHP	9	3.8778	3.20538	1.06846
	TBJS	9	3.8444	1.68383	.56128
PeakForce_diff	HHP	9	3.2856	3.27000	1.09000
	TBJS	9	3.9456	2.77237	.92412
RFD_diff	HHP	9	485.3333	411.59902	137.19967
	TBJS	9	655.1111	753.08822	251.02941
F50_diff	HHP	9	2.2222	1.52234	.50745
	TBJS	9	2.6500	2.54152	.84717
F100_diff	HHP	9	2.0622	1.68025	.56008
	TBJS	9	2.9656	2.54713	.84904
F150_diff	HHP	9	3.3467	2.19887	.73296
	TBJS	9	2.9356	2.34840	.78280
F200_diff	HHP	9	3.4111	2.12901	.70967
	TBJS	9	3.7189	2.54424	.84808
F250_diff	HHP	9	2.8022	2.42486	.80829
	TBJS	9	3.7511	2.52648	.84216

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
SJPeakP_diff	Equal variances assumed	.201	.660	-1.451	16	.166	-2.29444	1.58114	-5.64631	1.05742
	Equal variances not assumed			-1.451	14.738	.168	-2.29444	1.58114	-5.66979	1.08090
SJJH_diff	Equal variances assumed	.000	.988	-1.202	16	.247	-1.72222	1.43284	-4.75970	1.31526
	Equal variances not assumed			-1.202	15.981	.247	-1.72222	1.43284	-4.76000	1.31556
CMJPeakP_diff	Equal variances assumed	6.643	.020	-.522	16	.609	-1.16111	2.22398	-5.87574	3.55352
	Equal variances not assumed			-.522	10.187	.613	-1.16111	2.22398	-6.10413	3.78191
CMJJH_diff	Equal variances assumed	2.854	.111	.028	16	.978	.03333	1.20691	-2.52521	2.59187
	Equal variances not assumed			.028	12.103	.978	.03333	1.20691	-2.59383	2.66049
PeakForce_diff	Equal variances assumed	.000	.984	-.462	16	.650	-.66000	1.42902	-3.68939	2.36939
	Equal variances not assumed			-.462	15.583	.651	-.66000	1.42902	-3.69599	2.37599

RFD_diff	Equal variances assumed	3.690	.073	-.593	16	.561	-169.77778	286.07606	-776.23193	436.67638
	Equal variances not assumed			-.593	12.388	.564	-169.77778	286.07606	-790.92615	451.37059
F50_diff	Equal variances assumed	3.225	.091	-.433	16	.671	-.42778	.98752	-2.52123	1.65668
	Equal variances not assumed			-.433	13.086	.672	-.42778	.98752	-2.55977	1.70421
F100_diff	Equal variances assumed	1.912	.186	-.888	16	.388	-.90333	1.01714	-3.05957	1.25290
	Equal variances not assumed			-.888	13.854	.390	-.90333	1.01714	-3.08704	1.28037
F150_diff	Equal variances assumed	.173	.683	.383	16	.706	.41111	1.07238	-1.86223	2.68446
	Equal variances not assumed			.383	15.931	.707	.41111	1.07238	-1.86303	2.68525
F200_diff	Equal variances assumed	.922	.351	-.278	16	.784	-.30778	1.10583	-2.65204	2.03649
	Equal variances not assumed			-.278	15.518	.784	-.30778	1.10583	-2.65798	2.04242
F250_diff	Equal variances assumed	.063	.805	-.813	16	.428	-.94889	1.16729	-3.42343	1.52565
	Equal variances not assumed			-.813	15.973	.428	-.94889	1.16729	-3.42377	1.52599

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	SJPrePeakP - SJPostPeakP	-2.31500	3.46147	.81588	-4.03635	-.59365	-2.837	17	.011
Pair 2	SJPreJH - SJPostJH	-2.51667	3.07901	.72573	-4.04782	-.98551	-3.468	17	.003
Pair 3	CMJPrePeakP - CMJPostPeakP	-3.66278	4.54614	1.07154	-5.92352	-1.40204	-3.418	17	.003
Pair 4	CMJPreJH - CMJPostJH	-3.86111	2.48386	.58545	-5.09631	-2.62592	-6.595	17	.000
Pair 5	PreForceNorm - PostForceNorm	-3.61556	2.96044	.69778	-5.08775	-2.14336	-5.181	17	.000
Pair 6	PrePRFD - PostPRFD	-570.22222	595.18436	140.28630	-866.20044	-274.24400	-4.065	17	.001
Pair 7	Pre50ms - Post50ms	-2.43611	2.04419	.48182	-3.45266	-1.41956	-5.056	17	.000
Pair 8	Pre100ms - Post100ms	-2.51389	2.14423	.50540	-3.58019	-1.44759	-4.974	17	.000
Pair 9	Pre150ms - Post150ms	-3.14111	2.21705	.52256	-4.24363	-2.03860	-6.011	17	.000
Pair 10	Pre200ms - Post200ms	-3.56500	2.28129	.53771	-4.69946	-2.43054	-6.630	17	.000
Pair 11	Pre250ms - Post250ms	-3.27667	2.45136	.57779	-4.49570	-2.05763	-5.671	17	.000