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Augmented eccentrics: acute effects on jump performance

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Augmented Eccentrics: Acute Effects on Jump Performance

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Abstract

The purpose of this study was to examine the acute effect on countermovement jump performance when augmenting the eccentric load via the use of external resistance. Female subjects (n= 12) were recruited from the Western Washington University Division II NCAA volleyball team. The augmenting protocol involved the athletes holding Sandbells® at their side during the lowering phase, dropping them before the bottom of the countermovement, and immediately performing an explosive jump. The results indicated no significant effect of augmenting the eccentric phase with 28.98 ± 4.10 % of BW on performance measures that included: jump height, pre-load, modified RSI, peak power output (PPO), or concentric phase AveIEMG of either the vastus lateralis or medial gastrocnemius. Statistical analysis was carried out using paired samples t-tests, with an alpha value set a p = .01. Effect sizes showed a moderate effect of augmenting the eccentric phase on concentric medial gastrocnemius AveIEMG which needs to be interpreted with caution due to the non-significant difference in AveIEMG between conditions. The results demonstrated an ability to maintain performance with an augmented external load. Due to no significant performance enhancement in any of the measured variables it is suggested that AE protocols may not be ideal for female volleyball players but may still be valuable in more experienced jump trained populations.

Keywords: augmented eccentrics (AE), pre-load, countermovement jump (CMJ)

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Chapter I

The Problem and Its Scope

Introduction

During athletic events or activities of daily living, movement of the skeleton is accomplished primarily via the combined contributions of isometric, concentric and eccentric muscle actions (Moore & Schilling, 2005). Explosive activities usually rely on the enhancement of movement via a rapid pre-stretch or countermovement (Takarada, Hirano, Ishige, & Ishii, 1997). When a movement couples an eccentric action with a concentric action, it is termed a stretch shortening cycle (SSC) activity and results in an augmentation of concentric performance when compared to pure concentric movement (Aboodarda, Yusof, Abu Osman, Thompson, & Mokhtar, 2013; Bobbert, Gerritsen, Litjens, & Van Soest, 1996a; Fukashiro & Komi, 1987; Moran & Wallace, 2007). This pre-stretch can result in increased force production, greater power outputs, and increases in concentric work (Bobbert et al., 1996a; Cronin, McNair, & Marshall, 2001; Moran & Wallace, 2007). Understanding the patterns of kinetic and kinematic characteristics of the lower extremity are vital to understanding of the movement, and for optimization of training programs designed to elicit performance enhancement (Aboodarda et al., 2013; Earp et al., 2011; McMahon, Comfort, & Pearson, 2012; Moore & Schilling, 2005).

Mechanisms by which the countermovement can increase performance are still being debated. Proposed mechanisms include: increases in elastic energy storage and utilization, increased SSC reflex contribution, increase in the pre-load applied to the muscles during the eccentric phase (related to increased time for force development), as well as altered mechanical structures in the contractile element (Bobbert et al., 1996a; Bosco & Viitasalo, 1982; Cronin et al., 2001; Finni, Ikegawa, & Komi, 2001; Komi & Bosco, 1978; Moore & Schilling, 2005; Rassier, 2012). Typical athletic training to induce positive adaptations to the aforementioned aspects involves the implementation of plyometrics and traditional isoinertial explosive exercises (Cormie, McGuigan, & Newton, 2011). Recent evidence suggests that the use of augmented eccentric protocols may offer a more efficient method for producing adaptations favoring explosive performance (Friedmann-Bette et al., 2010).

Typical dynamic constant external resistance training, under-loads the eccentric phase of movement to accommodate the force-limiting concentric phase, and in turn, may limit maximal potential for adaptations for performance are being limited (Brandenburg & Docherty, 2002; Moore & Schilling, 2005). A recently developed training method that utilizes the eccentric intensity dependent characteristics, and has been gaining popularity, is the use of augmented eccentric (AE) training protocols (Aboodarda et al., 2013; Friedmann-Bette et al., 2010; Godard, Wygand, Carpinelli, Catalano, & Otto, 1998; Moore, Weiss, Schilling, Fry, & Li, 2007; Sheppard et al., 2008). This was defined as applying a heavy eccentric load immediately before a relatively lighter concentric load (Moore & Schilling, 2005). Although the augmented eccentric protocol was first investigated in the upper body, use of this training protocol has now been applied to the lower body (Aboodarda et al., 2013; Friedmann-Bette et al., 2010; Sheppard, Newton, & McGuigan, 2007). Currently there is a paucity of research investigating AE protocols during jumping movements (Aboodarda et al., 2013; Moore et al., 2007; Sheppard et al., 2008, 2007).

There are only three studies that have specifically investigated the use of AE protocols on jumping movements (Aboodarda et al., 2013; Moore et al., 2007; Sheppard et al., 2007). In all of these studies, males were utilized as test subjects, with varying methods used for calculations of jump height and peak power outputs. Two of the studies observed increases in jump height and peak power output (Aboodarda et al., 2013; Sheppard et al., 2007). Moore et al. (2007) conducted their study with males, however, they were only recreationally trained, which when compared to the jump trained athletes presents with a problem (Guillaume, Phillip, & Tom, 2013).

Due to the mixture of inconclusive results in the literature, this study is aimed at providing a biomechanical analysis of AE and free countermovement jumps (CMJ). This was done to investigate the acute effects that AE loading has on specific kinetic, kinematic, and myo-electrical characteristics in a female population.

Purpose of the study

The purpose of this study was to examine the effect of external loading during the eccentric phase of a CMJ on concentric performance measures. Specifically, we compared AECMJ to free CMJ. Variables used to compare the conditions included: pre-load (force at bottom of the CMJ), modified reactive strength index (RSI), peak power output (PP), jump height and average integrated EMG (AveIEMG) of the vastus lateralis (VL) and medial gastrocnemius (MG) during the concentric phase.

Hypotheses

The null hypothesis is that there will be no difference in pre-load, modified RSI, peak power-output, jump height, or concentric AveIEMG of the vastus lateralis or medial gastrocnemius between the bodyweight countermovement jump and the augmented eccentric countermovement jump.

Significance of the study

This investigation may give further insight into the mechanisms of lower body performance augmentation as well as possibly providing a basis for further research and empirical data to support the application of training programs utilizing AE in the performance and rehabilitation setting (Brughelli & Cronin, 2008; Kaminski, Wabbersen, & Murphy, 1998; McMahon et al., 2012; Moore & Schilling, 2005). This will be the first study to examine the concentric phase electromyography during augmented eccentric jumping protocols, possibly allowing for further elucidation of the mechanism behind performance enhancement observed in previous literature (Aboodarda et al., 2013; Sheppard et al., 2007).

Limitations of the study

1. Jumping during athletic activities is an open event whereas jumping in the lab on a force platform is a closed skill. The lack of comparability between the lab environment and real world situations was a limitation of this study.
2. The individual trials may induce potentiation or fatigue for subsequent trials and is recognized as a possible limitation of this study.

3. Maximal efforts were verbally encouraged throughout all trials, both augmented eccentric countermovement jumps and free countermovement jumps, but may not have been executed by all subjects on all trials.
4. Individual footwear and clothing equipment were not standardized. The subjects were instructed to wear athletic footwear and spandex shorts for consistent accuracy during the manual digitization process used for kinematic measurements.
5. Sleep patterns, nutritional status, and training activities of subjects were not standardized.
6. Due to the process of recruitment of NCAA Division II volleyball athletes from limited sources, a selection bias exists.
7. Due to the augmented load during the eccentric phase it is possible that the movement patterns were altered to compensate for this augmentation. To try and account for this, during the bodyweight countermovement jump, the arms were limited to a similar range as during the augmented eccentric countermovement jump.

Definition of terms

Augmented Eccentric (AE): Applying a heavy eccentric load immediately before a relatively lighter concentric load (Moore et al., 2007).

Countermovement Jump (CMJ): Starting from an erect position, the subject is allowed to flex into a squatting position, and encouraged to transition to the propulsive phase as quickly as possible (Moran & Wallace, 2007).

Drop Jump (DJ): Starting from an elevated platform, the subject drops from various heights before rapidly performing a countermovement jump upon landing (Moran & Wallace, 2007).

Extracellular matrix (ECM): Connective tissue surrounding the muscle, including proteins, glycoproteins and water (Gillies & Lieber, 2011).

Force Plate (FP): Force transducer mounted flush with laboratory floor, allowing for collection of ground reaction forces (Robertson et al., 2004).

Free Countermovement Jump (Free CMJ): A countermovement jump performed with only the subjects bodyweight as resistance (Sheppard et al., 2007)

Golgi Tendon Organ (GTO): Mechanoreceptor located in series with the tendon (Chalmers, 2004).

Half-Sarcomere (HS): The region from the M-line to the Z-line in skeletal muscle sarcomeres (Rassier & Pavlov, 2012).

Integrated EMG (IEMG): Integration of myo-electrical activity, allowing for quantification of muscle activity during a particular time interval (Bosco & Viitasalo, 1982).

Isointertial Training: Same load used for both the eccentric and concentric phases of an exercise (Moore et al., 2007)

Motor Unit (MU): An alpha motor neuron and all of the individual muscle fibers that it innervates (Kraemer, 2012).

Muscle Spindle (MS): Mechanoreceptors found in the intrafusal fibers of skeletal muscle that participate in proprioception and neural reflexes (Schiaffino & Reggiani, 2011).

PEVK Region of Titin: A proline, glutamate, valine, and lysine amino-acid rich segment of titin in the I-band thought to be responsible for Ca^{2+} binding allowing for increases in tension (Labeit et al., 2003).

Power: The amount of work in Watts produced per unit of time, or the product of force and velocity (Cronin, 2005).

Pre-Load: Force at the end of the eccentric phase of the countermovement jump (Bobbert et al., 1996a).

Residual force enhancement (RFE): An increase in isometric force following stretch (sarcomere, myofibril, or whole muscle both in-vitro and in-vivo) when compared to a pure isometric contraction at a corresponding length (Rassier, 2012).

Stretch Reflex: Mechanoreceptors, specifically muscle spindles, produce an excitation to afferent nerves, which travel to the spinal cord and cause stimulation of the efferent nerve to excite skeletal muscle (Zehr & Stein, 1999).

Stretch Shortening Cycle (SSC): Eccentric lengthening of muscle, followed immediately by concentric shortening (Bosco et al., 1982).

Squat Jump (SJ): Starting from a semi-squatting position, the subject performs a vertical jump with no preparatory movement, in turn eliminating any eccentric loading (shown by having negative work = 0) or stretch shortening cycle activation (Moran & Wallace, 2007).

Tendinous Tissue (TT): Connective tissue, including aponeurosis and tendons (Ishikawa, Komi, Finni, & Kuitunen, 2006)

Chapter II:

Review of Literature

Introduction

In athletic events involving jumping, it is crucial for an athlete to be able to produce large forces rapidly while performing high-velocity movements that have short time durations (Earp et al., 2011). Augmented eccentrics (AE) may be a useful technique to elicit greater acute and chronic physiological adaptations when compared to typical iso-inertial training, especially in trained athletes (Aboodarda et al., 2013; Friedmann-Bette et al., 2010; Hortobágyi, Devita, Money, & Barrier, 2001; Sheppard et al., 2008, 2007).

The use of varying jumping techniques has been used throughout the literature as a method for analyzing lower body performance (Asmussen & Bonde-Petersen, 1974; Bobbert et al., 1996a). Specific characteristics present during superior performance in the CMJ (jump height being the dependent variable) are: increased ground reaction force at the bottom of the countermovement, greater eccentric (negative), concentric (positive) and total work performed, greater power outputs, increased rates of force development (RFD), as well as increased movement times (Bobbert, Gerritsen, Litjens, & Van Soest, 1996b; Bosco & Viitasalo, 1982; J. Cronin & Sleivert, 2005; T Finni et al., 2001; Fukashiro & Komi, 1987; Hubley & Wells, 1983; P. V. Komi & Bosco, 1978; Kraemer & Looney, 2012; Moran & Wallace, 2007).

In this review, the purpose was to outline the structures and their functions essential for elastic energy storage, passive force development, and stretch shortening cycle (SSC) augmentation during dynamic movement. This was done to underline their importance in the application of AE loading protocols.

Review of Pertinent Literature:

Residual force enhancement. The contractile component cannot account for 100% of the force generation in human skeletal muscle, thus, other structures must be contributing (Anderson, Bogomolovas, Labeit, & Granzier, 2010; Huijing et al., 2010; Leonard & Herzog, 2010; Nishikawa et al., 2011; Passerieux, Rossignol, Letellier, & Delage, 2007). Residual force enhancement (RFE) is an increase in the steady state force after active stretch above the isometric force at a corresponding length of either a sarcomere, myofibril or whole muscle in-vitro and in-vivo (Herzog, Lee, & Rassier, 2006; Joumaa, Leonard, & Herzog, 2008; Nishikawa et al., 2011; Rassier, 2012) The concept of residual force enhancement has evolved since early experiments conducted to investigate the relationship between work performed and amount of energy liberated during shortening and lengthening muscle actions (Fenn, 1924). In a foundational study, Fenn (1924) observed decreases in energy liberated during eccentric muscle actions when compared to concentric muscle actions. This early finding suggested that the contractile element was not the only structure participating in RFE and led to further research to investigate other mechanisms to explain RFE during lengthening/eccentric muscle actions.

Abbott and Aubert (1952) were one of the first to investigate novel mechanisms to explain RFE in skeletal muscle. They conducted studies on toad sartorious muscles to examine differences between eccentric, isometric, and concentric muscle actions (Abbott

& Aubert, 1952). They found an increase in steady-state tension in toad sartorious muscles after imposing different rates of stretch, leading to muscles with increased tension (57-58 g) above the isometric values at the same lengths (28g) (Abbott & Aubert, 1952). These increases in tension with stretch led to the proposal of the sarcomere length (SL) non-uniform hypothesis (Abbott & Aubert, 1952; Edman, Elzinga, & Noble, 1978). The sarcomere-length non uniformity hypothesis proposes that within a myofiber, sarcomeres can have varying lengths, independent of each other. They hypothesized this non-uniformity could result in varying tension along the myofiber, with the stronger sarcomeres stretching the weaker sarcomeres (Abbott & Aubert, 1952). These results were supported by further research conducted on activated stretch of single frog semitendinosus muscle fibers, resulting in similar observations of increased tension in the stretched fibers as compared to the fibers activated isometrically at the final stretch length (Edman et al., 1978). The findings of these studies warranted further research to find a mechanism to explain this non-uniformity (Morgan, 1990).

Originally, the SL non-uniformity included the tenet that sarcomeres would develop different lengths during activation. This would allow for exploitation of the properties of the force-length relationship. Morgan (1990) used a computer model based on A.V. Hill's classical contraction equations to simulate an activated stretch on a fiber of sarcomeres in series (1, 100, or 500). This stretch resulted in non-uniform elongation of sarcomeres individually from weakest to strongest leading to a "popping" of the weaker sarcomeres (Morgan, 1990). Popping occurred when the sarcomeres were stretched beyond a length allowing for overlap of actin and myosin. This would lead to an increase in force due to passive elements and a portion of the sarcomeres being left at higher active tensions (Campbell, Hatfield, & Campbell, 2011; Morgan, 1990) The theory of "popping" sarcomeres states that when a sarcomere "pops", it no longer develops active tension because there is no longer filament overlap. This suggested that passive structures generate tension in the "popped" sarcomeres. Early computer models used to investigate RFE that included popping helped explain the increases in force seen with stretch. This has been refuted with current research investigating other mechanisms to explain SL non-uniformity (Cornachione & Rassier, 2012; Rassier, Herzog, & Pollack, 2003).

Although the SL non-uniformity theory has provided researchers with explanations for unexplained phenomena, the inclusion of the "popping" was a controversial tenet of the theory. Rassier, Herzog, & Pollack (2003) provided evidence contrary to the "popping" theory with research on single myofibrils from rabbit psoas muscle. This was done with constant length measurements of each sarcomere provided by a linear 1024-element photodiode array. Their goal was to investigate the stability of the sarcomere as well as the non-uniformity in SL. A sarcomere was considered stable if the range of length change (defined as the difference between the longest and shortest SL) was smaller than 0.1µm, and length changes during shortening or lengthening were random (Rassier et al., 2003). Upon stretching the activated fibers, individual SL changes were less than 0.1µm with a mean maximal dispersion of 0.016 ± 0.001µm, indicating a stable sarcomere (Rassier et al., 2003). Another finding of this study that contradicts the "popping" theory was demonstrated by sarcomere lengths never going beyond 3.87µm. In the 110 sarcomeres observed in this study, none showed lengthening beyond myofilament overlap (SL>3.87µm) (Rassier et al., 2003). Three sarcomeres from three separate myofibers stretched to lengths of 3.34, 3.33 and 3.27µm respectively, while the other 107 sarcomeres did not stretch beyond 3.22μm (Rassier et al., 2003). This provides empirical evidence that sarcomeres do not lengthen beyond 3.87 μm. These results helped shift the focus of the research from investigating sarcomere length non-uniformity at the whole sarcomere level, to investigating non-uniformity at the half-sarcomere level (Campbell et al., 2011; Rassier, 2012).

Campbell, Hatfield, & Campbell (2011) used a computer model (based on rabbit psoas myofibers) of 50 half-sarcomeres (HS) in series to investigate new mechanisms to explain residual force enhancement. They used a 2% variation in HS length and found enhancements of residual force development in all portions of the force-length relationship up to 13% (Campbell et al., 2011). This demonstrates the importance of HS heterogeneity in the developing theory of SL non-uniformity as a mechanism for RFE (Campbell et al., 2011). This study utilizing computer models of HS non-uniformity prompted in-vitro research of half-sarcomeres (Cornachione & Rassier, 2012; Minozzo, Baroni, Correa, Vaz, & Rassier, 2013; Rassier & Pavlov, 2012).

Rassier & Pavlov (2012) investigated the role of non-uniformity in the HS and its contribution to residual force enhancement in single sarcomeres and multiple sarcomeres in series. They used myofibrils with known number of sarcomeres and a pair of pre-calibrated micro-needles attached adjacent to the z-lines. Upon activation, the samples were allowed to develop tension for one second, and then stretched 5-10% of initial SL at a rate of 0.3μm/s/SL. When testing single sarcomeres, 31 of the 59 fibers showed RFE, with 28 showing no RFE. In the fibers showing RFE, they observed a mean force enhancement of 10.46 ± 0.78% following stretch, which is consistent with previous predictions by computer models (Campbell et al., 2011; Rassier & Pavlov, 2012). When analyzing all of the 59 fibers tested as one, there was still a mean force enhancement of 5.24 ± 0.83% (Rassier & Pavlov, 2012). In comparison to single sarcomeres in series, two sarcomeres in series resulted in a greater RFE of 23.89% observed in one sample, however, not all samples showed RFE (Rassier & Pavlov, 2012). Finally, when sarcomeres were in series of three or more, RFE was always observed with levels of 27.55-31.19% for the examples shown. The observed RFE in three or more sarcomeres in series was linearly correlated with the degree of HS non-uniformity (Rassier & Pavlov, 2012). This correlation underlines the importance of HS non-uniformity and its role in RFE. These observations were corroborated by later research showing that, even in a single HS, there was a significant increase in the force produced during stretch following activation (adjusted mean = 37.6 ± 2.1 $nN/\mu m^2$) and isometric activation (adjusted mean = 24.6 ± 3.6 $nN/\mu m^2$) (Minozzo et al., 2013)**.** The significant increases in RFE observed during in-vitro studies warranted in-vivo studies of RFE (Hahn, Seiberl, Schmidt, Schweizer, & Schwirtz, 2010; Seiberl, Paternoster, Achatz, Schwirtz, & Hahn, 2013; Shim & Garner, 2012)**.**

Shim and Garner (2012) investigated RFE in large thigh muscles during knee extension tasks utilizing an isokinetic device. A statistically significant RFE was observed during voluntary contractions with increases of 4-5% over pure isometric values during knee extension exercise (Shim & Garner, 2012). They utilized a slow stretch of 30°/s from 70° to 100° of knee flexion, to stretch the muscle upon activation to 10% of the maximum isometric value (Shim & Garner, 2012). Observed increases in RFE during single joint exercises lead to the investigation of RFE in multi-joint exercises (Hahn et al., 2010; Seiberl et al., 2013).

Hahn, Seiberl, Schmidt, Schweizer, & Schwirtz (2010) used a motor-driven leg press dynamometer, as well as a force plate, muscle activation and inverse dynamics measurements to study the effect of adding a stretch of 20° at 60°/s upon muscle activation of 95% during leg press tasks in young, healthy male subjects. The authors reported a significantly enhanced extension force (23.1 ± 7.3%) at end of stretch even after correcting for hip, knee and ankle joint flexion. The RFE values for three different time periods following stretch were reported: 0.5-1 (FS1), 1.5-2 (FS2), and 2.5-3 (FS3) seconds (Hahn et al., 2010). In both the knee and ankle joint, significant increases in torque and force of extension were observed for all three time-periods. During FS1, FS2, and FS3, force of extension was significantly enhanced by 12.3 ± 19.5%, 8.5 ± 7.7%, and 6.3 ± 6.2%, respectively. Seiberl, Paternoster, Achatz, Schwirtz, & Hahn (2013) performed a follow up study with similar methods finding significant increases in force of extension for up to 22 seconds post stretch, as well as significant increases in torque at both the knee and ankle. These results, utilizing multi-joint assessment of RFE, support the role of RFE during everyday movement and highlight the need to elucidate the force enhancement phenomena following stretch in-vivo (Joumaa & Herzog, 2013).

Recently, research was conducted to investigate the metabolic cost of force production after active stretch in skinned rabbit psoas myofibers (Joumaa & Herzog, 2013). When comparing a purely isometric condition to a stretch-isometric condition, there were significant ($p < .05$) decreases in ATPase activity (17.2 ± 4.1%) during the stretch condition, as well as increases in passive (29.5 ± 4.2%) and residual force enhancement (11.3 ± 3.6%). This increased efficiency in cross bridge kinetics and increased reliance on passive elements can allow for superior force production in actions involving a stretch as compared to isometric alone (Joumaa & Herzog, 2013). Currently, the mechanism behind residual force enhancement is still being debated, however, the theory of RFE includes two prominent components: sarcomere length non-uniformities, and sarcomeric structures passively contributing to the RFE (Campbell et al., 2011; Minozzo et al., 2013).

Sarcomeric proteins contributing to RFE. Residual force enhancement is highly dependent on sarcomeric proteins that contribute to force generation through passive force enhancement. The giant protein, titin, plays an important role in passive force development as well as acting as a template for sarcomere development during myogenesis (Chandra et al., 2009; Cornachione & Rassier, 2012; Joumaa et al., 2008; Kontrogianni-Konstantopoulos & Bloch, 2005; Rassier, 2012; Schiaffino & Reggiani, 2011). Titin is the most studied sarcomeric protein and is very important in its contribution to passive force development. Other sarcomeric proteins such as nebulin and desmin have also been identified as passive force generators (Bär, Strelkov, Sjöberg, Aebi, & Herrmann, 2004; Chandra et al., 2009; Grounds, Sorokin, & White, 2005; Minozzo et al., 2013; Nishikawa et al., 2011; D. E. Rassier, 2012; Small & Gimona, 1998)

Intermediate filaments including desmin, and structural proteins including nebulin, participate in passive force production and transmission (Chandra et al., 2009; Grounds et al., 2005; Paulin & Li, 2004). Nebulin is a giant protein that spans from the z-disk (c-terminal) to varying points on actin (n-terminus), and has been implicated in increased thin filament activation with a mechanism that includes alterations to cross bridge cycling kinetics (Boriek et al., 2001; Capetanaki, Bloch, Kouloumenta, Mavroidis,

& Psarras, 2007; Crawford & Horowits, 2011; Grounds et al., 2005). In a study comparing force generation properties of skinned muscle fibers from nebulin knockout mice (NEB KO) to wild type (WT) mice, it was shown that the wild type mice (containing nebulin) were able to produce significantly greater tension, and stiffness. The WT mouse produced those greater tensions and stiffness at a reduced metabolic cost (Chandra et al., 2009). This study demonstrates the importance of nebulin in passive force enhancement. Without a highly organized protein system to transmit these forces to the basal lamina or extra cellular matrix (ECM), the increase in force would be wasted (Boriek et al., 2001; Chandra et al., 2009; Grounds et al., 2005).

In helping to transmit the force produced in the sarcomere to the basal lamina and ECM, structures like desmin must be present. Desmin is an intermediate filament muscle specific protein and helps form the scaffold around the z-lines and links myofibers laterally by providing a connection between z-lines (Bär et al., 2004; Boriek et al., 2001; Capetanaki et al., 2007; Grounds et al., 2005; Paulin & Li, 2004; Small & Gimona, 1998). Though nebulin and desmin are important, it is the structure and function of titin that is most valuable when understanding RFE, passive force enhancement (PFE) and storage and usage of elastic energy (Cornachione & Rassier, 2012).

Titin, the largest known protein in the myofibril, at 3-4MDa, spans from the M-line in the A-band to the Z-line in the I-band, and is the third most prolific protein in striated muscle (Bianco et al., 2007; Gregorio et al., 1998; Joumaa, Rassier, Leonard, & Herzog, 2008; Leonard & Herzog, 2010; Nishikawa et al., 2011; Ottenheijm et al., 2012; Schiaffino & Reggiani, 2011). Due to the overlapping of adjacent titin molecules in the m-line (carboxyl-terminal regions) and z-line (amino terminal regions), titin forms a continuous filament system spanning the entire myofiber (Gregorio et al., 1998; Gregorio, Granzier, Sorimachi, & Labeit, 1999; Labeit & Kolmerer, 1995; Nishikawa et al., 2011; Tatsumi, Maeda, Hattori, & Takahashi, 2001). Titin has a resting sarcomere length of 2.1-3.5 µm (depending on the isoform). The length at which titin increases its passive tension varies with the different isoforms allowing for exploitation of titin's varying elastic properties (Gregorio et al., 1999; Nishikawa et al., 2011).

Titin's ability to engage in passive force development is derived from its structure and how it connects with other sarcomeric proteins involved in muscle actions. Specifically, titin's N2-A and PEVK regions have garnered interest due to their ability to modulate titin-based stiffness in skeletal muscle via a Ca^{2+} regulated mechanism (Bianco et al., 2007; Cornachione & Rassier, 2012; Gregorio et al., 1999; Joumaa, Rassier, et al., 2008; D. Labeit et al., 2003; Leonard & Herzog, 2010; Linke et al., 2002; Nishikawa et al., 2011; Rassier, 2012). Currently, there are two hypothesized mechanisms for enhancement of passive force by titin; Ca^{2+} regulated stiffening of the PEVK region and Ca^{2+}-induced binding of titin to actin leading to an increase in stiffness of the sarcomere (Berthier & Blaineau, 1997; Bianco et al., 2007; Cornachione & Rassier, 2012; Gregorio et al., 1998; D. Labeit et al., 2003; Nishikawa et al., 2011; Schiaffino & Reggiani, 2011; Tatsumi et al., 2001). The mechanism associated with titin's enhancement of passive force development is still being elucidated. In the last ten years, a considerable amount of knowledge has been gained due to technological advancements.

Joumaa, Rassier, Leonard, & Herzog (2008) attempted to examine titin's role in passive force development using single rabbit psoas muscle fibers with intact troponin-c (TnC) as well as TnC depleted fibers. This was done to investigate passive force enhancement (PFE) when active force generation had been inhibited due to deletion of the TnC protein. To verify whether the active force had been eliminated, tests of activation at lengths of 2.4μm and 3.4μm were performed, showing normal length-tension curves prior to deletion, with no force generation after deletion (Joumaa, Rassier, et al., 2008). The results showed an increase in PFE of approximately 25-30% in an activating solution (pCa 3.5), as compared to the relaxing solution. This indicates that in the absence of active force, Ca^{2+} is still required for PFE (Joumaa et al., 2008). The fibers were also tested after trypsin was added to degrade titin. This resulted in the abolishment of the PFE seen with addition of Ca^{2+} and a large decrease in passive force of approximately 20% produced by intact fibers (Joumaa et al., 2008). This large decrease in passive force enhancement following the deletion of titin suggests that PFE is mediated by inherent mechanical properties of titin. These results demonstrate the presence of PFE when TnC was depleted, eliminating active RFE; with the greatest PFE (25-30%) observed if Ca^{2+} was present (Joumaa et al., 2008). This spurs the suggestion that passive force enhancement not only requires the Ca^{2+} influx, but requires active cross bridge formation to fully engage titin's role in passive force enhancement (Joumaa et al., 2008).

Continuing the investigation of titin's role in PFE, Leonard and Herzog (2010) used individual myofibers from rabbit psoas muscles to determine the contribution of titin to the forces (expressed as stress and normalized to the cross-sectional area in their study to $nN/\mu m^2$) produced during lengthening using multiple solution preparations. The solutions included: activated at 2.4 μm, activated at 3.4 μm, non-activated, activated with a cross bridge inhibitor butanedione monoxime (BDM), a non-activated solution containing trypsin (causing titin deletion), or an activated trypsin containing solution. An important finding from the study was not that the activated and stretched myofibers had a larger stress than the non-activated and stretched myofibers in overlap zone (<4µm), but the actively stretched fibers maintained these high stresses, increasing with more intensity beyond the actin and myosin overlapping zone (>4 µm) (Leonard & Herzog, 2010). This unexpected increase in force generation beyond the myofilament overlapping zone was further explained in the next set of experiments by controlling titin's role in force generation, by adding trypsin to the activating or non-activating solution (Leonard & Herzog, 2010). This resulted in almost zero force at any length, consistent with previous research and further supporting the role of titin as a passive force enhancing element (Joumaa et al., 2008; Leonard & Herzog, 2010).

The investigation into the mechanism and role of this passive element was continued with another set of experiments allowing for activation at different lengths (Leonard & Herzog, 2010). Starting at 2.4µm, rabbit psoas muscle myofibers were either activated and stretched beyond myofilament overlap, or stretched to 3.4 µm before activation and stretching beyond myofilament overlap. The resulting stress/length curves showed greater stress achieved and maintained with the activation from 2.4 µm, when compared to the fiber activated at 3.4 µm (approximately 40% less) (Leonard & Herzog, 2010). This is in agreement with previous research, with the authors theorizing that there must be activation present for titin to elicit the greater PFE responses seen with the activated and stretched fibers (Joumaa et al., 2008; Leonard & Herzog, 2010). Multiple theories on Ca^{2+}-regulated binding to titin that elicit RFE have been proposed, however, no conclusive mechanism has been defined (Cornachione & Rassier, 2012).

Cornachione and Rassier (2012) investigated single permeabalized rabbit psoas muscle fibers treated with gelsolin (to extract actin filaments) to expand on the mechanism of titins role in PFE. Fibers treated with gelsolin still showed a significant increase in stiffness following a stretch when compared to pure isometric values. These results suggest that some passive element is still producing PFE. Titin may accomplish this through a Ca^{2+}-mediated conformational change in the PEVK region, specifically in the glutamate-rich E-regions (Cornachione & Rassier, 2012; Labeit et al., 2003; Rassier, 2012). These conformational changes in the PEVK region can influence the persistence length of the PEVK segment, which can increase stiffness, which in turn allows for increases in passive force production (Labeit et al., 2003).

Although the mechanism for RFE is still being debated, the proposal of sarcomeric proteins possessing adaptable elastic properties is consistent with other soft tissue structures in the human body. The role of elastic energy storage in human movement has been a primary area of investigation for an extended time. Recent research into the structures participating in elastic energy storage and their function during movement has provided new information for the debate on mechanisms involved in both RFE and PFE.

Elastic energy storage. Increased storage of elastic energy has been identified as one of the prominent mechanisms for performance augmentation in movements that incorporate a countermovement (Ishikawa & Komi, 2004; Komi & Bosco, 1978; Kubo, Kawakami, & Fukunaga, 1999; Lindstedt, Reich, Keim, & LaStayo, 2002; Morgan & Proske, 1997; Wilson & Flanagan, 2008). The storage of elastic energy occurs during an eccentric action, as the elastic components deform and resist the motion while the contractile component shortens or remains quasi-isometric (Cavagna, Dusman, & Margaria, 1968; Finni et al., 2001; Ishikawa & Komi, 2004; Kawakami, Muraoka, Ito, Kanehisa, & Fukunaga, 2002; Komi & Bosco, 1978; Kubo et al., 1999; Kurokawa, Fukunaga, & Fukashiro, 2001; Roberts, 2002; Wilson & Flanagan, 2008). Tendons (the series elastic element) are usually the primary focus of elastic energy research; however, recent evidence from invasive studies performed on animals is suggesting a greater role of the extra cellular matrix (ECM) participating in the storage and reutilization of elastic energy during force transmission (Huijing, 1999; Tian, Herbert, Hoang, Gandevia, & Bilston, 2012)

The structures participating in elastic energy storage are the connective tissues embedded in the muscle ECM consisting of a network of macromolecules, fibrous proteins, and a polysaccharide gel (Gillies & Lieber, 2011; Huijing, 1999). Classically, the muscle ECM is presented as three different layers of connective tissue: epimysium, perimysium, and endomysium (Huijing, 1999; Passerieux et al., 2007; van der Wal, 2009). Evidence from animal and human studies demonstrated that it is difficult to completely separate all three layers and it is now being argued that each of the these layers participate as part of the parallel elastic or series elastic component (Huijing, 1999; Raspanti, Ottani, & Ruggeri, 1990; van der Wal, 2009; Wilson & Flanagan, 2008).

Epimysium encases the entire muscle and each myofiber is surrounded by endomysium, which forms a honeycomb lattice and helps with lateral force transmission (Gillies & Lieber, 2011; Huijing, 1999). Perimysium, the connective tissue surrounding fascicles of muscle fibers also has a role in lateral force transmission. Passeriux et al. (2007) examined perimysium in bovine flexor carpi radialis after selectively removing the myofiber and observed that perimysium can participate in both lateral and in-series force transmission due to the continuity with the tendon itself. The structures participating in this force transmission are primarily the proteins found in the ECM.

The primary types of protein found in the ECM are collagens. Collagens are the most abundant proteins in the human body and are made up of three polypeptide chains in a triple helix (Franchi, Trirè, Quaranta, Orsini, & Ottani, 2007). Of the multiple types of collagen, the most abundant in human skeletal muscle are the fibrous types I and III, with perimysium being primarily constituted of type I (Gillies & Lieber, 2011). Collagen, which is considered a connective tissue, is now being grouped into a larger umbrella term, fascia (Schleip, Klingler, & Lehmann-Horn, 2005). This allows for a better description of what is actually occurring in-vivo, without delineating between the layers. This is very important due to evolving concepts of continuity between the layers of connective tissue, allowing for force transmission laterally and in series (Findley, Chaudhry, Stecco, & Roman, 2012; Huijing, 1999; Passerieux et al., 2007; Schleip et al., 2005; van der Wal, 2009). Schleip et al. (2006) hypothesizes that with recent evidence of the ability of fascia to act in a smooth muscle like manner, fascia participates in force transmission in ways previously unknown (Schleip et al., 2005; Spector, 2001). This ability of the fascial network to transmit forces is highly valuable when considering elastic energy storage and reutilization.

Elastic energy is defined as the capacity for an elastic structure to perform work during its reformation (Fukashiro & Komi, 1987). Elasticity, however, defined as how readily a body will regain its original shape after it has been deformed during a stretch, compression or twist (Wilson & Flanagan, 2008). Utilization of a countermovement increases the stored amount of elastic energy. Early research comparing movements with and without countermovement demonstrates an increase in storage of elastic energy which can be manifested as an increase in the amount of mechanical work done during each phase (Asmussen & Bonde-Petersen, 1974; Hubley & Wells, 1983; Nagano, Komura, & Fukashiro, 2004). Currently, two mechanisms have been proposed to explain increases in work done during jumping with a countermovement (CMJ and DJ) compared to jumps without a countermovement (SJ). Increased time available during the countermovement allows for greater preload of the musculature, and during the eccentric phase, negative work is done on the series and parallel elastic components to store energy that can be reutilized during the concentric phase (Taija Finni, Ikegaw, Lepola, & Komi, 2001; Lindstedt et al., 2002; Wilson & Flanagan, 2008). Research into the role of elastic energy storage in human multi-joint movement was preceded by investigations of single fibers from animal species.

Cavagna, Dusman, & Margaria (1968) investigated the effect of a pre-stretch on positive work performed in an isolated sartorii muscle of a toad and gastrocnemius of a frog. When proceeding a shortening contraction, lengthening of the toad sartorii muscles resulted in increases in the amount of concentric work (W') performed over that of a concentric action following isometric activation (W) (Cavagna et al., 1968). Observed ratios of W'/W reached values of 1.5 to 2.3. This indicates that with stretch, a muscle can perform more work in the concentric phase and produce greater performance as measured by increases in jump height (Asmussen & Bonde-Petersen, 1974).

Asmussen & Blonde-Petersen (1974) investigated the storage of elastic energy in human muscles, and found a significant interaction between increasing the amount of negative change in energy and increasing jump height. They performed this experiment by having their subjects jump from five different positions. The positions were: a semi-squatting position (SJ), countermovement jump (CMJ), and depth jumps from various heights. All jumps were performed on a force platform to allow for calculation of negative change in energy, positive change in energy, and jump height. They found that as the negative change in energy increased by adding either a preparatory countermovement or, a drop down from an elevated position, their jump height would increase (Asmussen & Bonde-Petersen, 1974). The average jump height increased from 0.366 m during the SJ, to 0.386 m during the CMJ, to 0.396 m when dropping from 0.233 m and 0.408m when dropping from .404 m (Asmussen & Bonde-Petersen, 1974).

Komi & Bosco (1978) conducted similar research on female and male physical education students, as well as elite male volleyball players. In all groups, SJ was significantly less efficient in producing performance than the CMJ and DJ, which is similar to the aforementioned study (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978). In the female subjects, the DJ from 50 cm gave the highest positive energy value of 147.2 J, while in the male groups, the CMJ showed the highest positive energy value of 297.9 J, and 352.2 J for the male volleyball players. When comparing the change in positive energy from CMJ to the SJ, there were increases of 23.0 J, 35.5 J, and 50.3 J for the female, male, and elite male volleyball players, respectively. This increase in positive energy during the concentric phase brings about an interesting trend observed when comparing the physical education students and the elite male volleyball players. The trained subjects performed better and responded better to the different conditions. For example, the male volleyball players had greater positive energy (301.9 J) during the

SJ than the male students did during the CMJ (297.9 J), indicating the male volleyball players performed better even without a preparatory movement. This highlights the importance of using trained subjects for studies investigating movements of this nature (Komi & Bosco, 1978). These early studies into elastic energy storage lead to more advanced inverse dynamic studies and continuing investigation into the mechanisms behind these increases seen with increasing negative energy (Bobbert et al., 1996b; Moran & Wallace, 2007).

Bobbert, Gerritsen, Litjens, & Van Soest (1996) conducted one of the more prominent studies on jump performance enhancement via increases in the rate of loading, and thus increasing the storage and utilization of elastic energy. For this study, six elite male volleyball players were used as subjects due to their jump training history. This is noteworthy because as mentioned previously, athletes with jump histories should be used for studies comparing maximal jump heights (Asmussen & Bonde-Petersen, 1974). In each of the four conditions used (CMJ, SJ from starting CMJ position, SJ from preferred position, and SJ from deepest squat possible) hands were kept behind the back to minimize input from the upper extremities as arm movement can augment jump performance (Feltner, Fraschetti, & Crisp, 1999).They found that the CMJ produced significantly greater jump height than the SJ due to a significantly greater vertical velocity at takeoff, as well as the CMJ producing significantly greater moments of torque at the ankle, knee and hip at the beginning of push-off causing a significantly greater GRF at that point (increased pre-load) (Bobbert et al., 1996b). The mean GRF at the start of push off during CMJ was 1708 ± 336 N as compared to 1006 ±218, 1187 ±335, or 905 ± 142 N for the SJ from same starting position of CMJ (SJC), SJ from preferred posture

(SJP), and a SJ from a deep position (SJD), respectively. They concluded that, due to the increased joint moments, the CMJ allows the subject to conduct more work during the propulsive phase thus leading to enhanced performance. Bobbert et al. (1996) proposed that the CMJ may be too slow of a movement to cause a concentric potentiation which is in disagreement with results from the literature using different loads to compare bench press throws (concentric motion only) to rebound bench press throws allowing for a countermovement (Cronin et al., 2001). Cronin, McNair, & Marshall (2001), found that when using a load of 80% 1-RM during a rebound bench press throw, stretch induced augmentation was observed up to 460ms after start of concentric phase. This demonstrates that even a slower movement can be augmented via pre-stretch with a higher load (Cronin et al, 2001). Results reported by Bobbert et al. (1996) and supported by Cronin et al (2001) pertaining to increases in work and the possible mechanisms behind the increases have been supported by current literature (Moran & Wallace, 2007).

Moran & Wallace (2007) showed that, with increasing eccentric intensity (SJ<CMJ<DJ), the amount of total work performed at the knee joint increased from 4.60 ± 0.87 to 5.09 ± 0.52 to 5.86 ± 0.83 J/ kg, respectively. These increases in work were seen simultaneously with significant increases in jump height for both knee angle conditions measured (70° and 90° of knee flexion during the countermovement). The 70° knee flexion condition produced significantly greater differences in jump height than the 90° condition. This finding suggests that using a shorter range of motion may allow for greater contribution of the knee joint to overall work production as demonstrated by the increase in knee joint moment during the 70° condition (SJ<CMJ<DJ) but no enhancement during the 90° knee flexion condition (Moran & Wallace, 2007). Although

there has been a large amount of research conducted on the relationship between work and elastic energy storage, recent technological advances have led to new studies involving ultrasonography to study tendon and muscle lengths during dynamic movement's in-vivo (Arakawa, Nagano, Yoshioka, & Fukashiro, 2010; Taija Finni et al., 2001; Ishikawa et al., 2006; Kurokawa et al., 2001).

Multiple studies have utilized ultrasonography to examine the fascicle and musculo-tendinous unit elasticity during dynamic movement (Arakawa et al., 2010; Taija Finni et al., 2001; Ishikawa et al., 2006; Kurokawa et al., 2001). Finni, Ikegawa, Lepola, & Komi (2001) used a unilateral sledge apparatus during SJ, CMJ, and DJs to investigate the changes in length of the fascicles and muscle-tendinous unit, while simultaneously measuring the patellar tendon force using an optical fiber transducer. Although the use of fascicle length does not give a direct measurement of muscle fiber length, ultrasonography techniques provide detailed information about in vivo muscular function. The authors found an inverse relationship between the patellar tendon force and the fascicle length during the concentric phase. These results were expanded on in an article by a few of the same authors later that year.

Finni, Ikegawa, & Komi (2001) utilized both maximal and submaximal conditions during knee extensions and unilateral jumping movements performed on a sledge to monitor in-vivo changes to the muscle-tendon unit. The maximal knee extension torque was enhanced significantly at 115° following a pre-stretch during the knee extension exercise with a corresponding significant increase in fascicle length prior to the concentric phase with final lengths of 16.8 ± 5.7 vs. 12.7 ± 2.9 cm, and a subsequently significant enhanced shortening (3.4 cm) during the concentric phase over the isometric condition (Finni et al., 2001). In the jumping movements, the CMJ produced a significantly greater change in fascicle length during the eccentric phase (3.5 ± 0.5 cm) than the repetitive jumps (2.5 ± 0.3 cm) as well as a greater change in fascicle length during the concentric phase (3.3 ± 0.5 cm vs. 1.8 ± 0.5 cm, respectively). Electromyography data, as well as fascicle length data for the repetitive jumps, revealed some interesting implications for SSC movement on how the body handles elastic energy storage.

With repetitive jumps, the EMG activity during the eccentric phase increased simultaneously with significant increase in force (460N) during the breaking phase of the jump (Finni et al., 2001). This indicates that as the eccentric intensity is increased, the ability to produce force increases. Fascicle length changes during the repetitive jumps were also significantly lower, suggesting that with an enhanced activation associated with a more intense SSC exercise, less fascicle lengthening occurs at the expense of tendinous-tissue (TT) lengthening due to the greater extent of activation and ability to resist motion, thus possibly deforming the series and parallel elastic components to a greater extent (Finni et al., 2001). Ishikawa et al. (2006) found similar results when investigating the effect of different multi-joint SSC movements on fascicle and tendon tissue interactions. When comparing their reference drop jump to the higher rebound condition, there was no increase in EMG activation during the early braking phase, but a significant increase in EMG activation during the late braking phase (Ishikawa et al., 2006). Observed simultaneously with a decrease in fascicle shortening, there was an increase in TT lengthening, with the lengthening being suggested by the author to take place primarily in the aponeurosis (Ishikawa et al., 2006).

The enhanced storage of elastic energy that could be occurring in the aponeurosis may contribute to increases in work to a greater extent than previously considered. The increase is accomplished by a combination of the structures embedded in the ECM and in the contractile component (Wilson & Flanagan, 2008). Contributions of the elastic energy to performance enhancements seen in AE protocols may also be potentiated by adding an accentuated load to the eccentric phase, resulting in altered neural stimulation dynamics (Moore & Schilling, 2005).

Neuromuscular (Stretch Shortening Cycle) enhancement. The muscular system's main function of controlling the skeleton is manipulated and activated by the nervous system, utilizing three main types of activation: postural joint stabilization, sustained activation such as breathing, and quick powerful-actions such as jumping (Schiaffino & Reggiani, 2011). The functional unit of the nervous system that interacts with the muscular system is the motor unit, a single α-motor neuron and all the individual myofibers that it innervates (English & Wolf, 1982; Schiaffino & Reggiani, 2011; Wakeling, 2004). Through SSC actions, the ability to store and utilize elastic energy in the extra cellular matrix (ECM) is influenced by various peripheral receptors providing afferent feedback. Muscle is activated to resist length changes that are accommodated by the series and parallel elastic components (Komi & Gollhofer, 1997).

In movement of the body, peripheral mechanoreceptors, such as golgi tendon organs and muscle spindles, have received much of the attention when considering afferent input from the peripheral nervous system to control human movement (Duchateau, Semmler, & Enoka, 2005; English & Wolf, 1982; Proske & Gandevia, 2012). Spindles are mechanoreceptors located within skeletal muscle, and wrapped around intrafusal fibers, and are constantly providing information to the CNS via primary afferent neurons about length of muscle and rate of length change (Blackburn, Padua, & Guskiewicz, 2008; Burke, Hagbarth, & Löfstedt, 1978; Chalmers, 2004; Hunt, 1990; Rumsey, Das, Bhalkikar, Stancescu, & Hickman, 2010; Wilson & Flanagan, 2008). Stretch causes increases in the afferent discharge rate, which in turn triggers an increase in activation of α-motor neurons resulting in greater force being achieved in the contractile element. This is termed a stretch reflex and is identified as a possible contributor to force augmentation during dynamic explosive movements (Chalmers, 2004; Hunt, 1990; Komi & Gollhofer, 1997; Proske & Gandevia, 2012).

Using a stretch initiates higher activation of the muscle during the eccentric phase and may lead to greater recruitment of high threshold motor units due to the increase in stimulation according to the Henneman size principle (Henneman, Somjen, & Carpenter, 1965; Walshe, Wilson, & Ettema, 1998; Wilson & Flanagan, 2008; Zehr & Stein, 1999). Two types of SSC activation have been identified: fast SSC (<.25 seconds) and slow SSC (>.25 seconds). To monitor this change in activation electromyography is usually employed (Chalmers, 2008; Chalmers, 2004; Duchateau & Baudry, 2013; Hunt, 1990; Linnamo, Moritani, Nicol, & Komi, 2003)

Measuring muscle activation with EMG provides researchers with a measurement that relates to muscle contractile activity (Chalmers, 2004). Multiple studies have indicated that trained subjects typically display better myo-electrical potentiation and performance enhancement during jumping activities than untrained subjects (Asmussen & Bonde-Petersen, 1974; Bosco & Viitasalo, 1982; Cavagna et al., 1968; Heikki Kyröläinen & Komi, 1995). Bosco & Vittaslo (1982) investigated myo-electrical of the gluteus maximus, rectus femoris, vastus lateralis, vastus medialis, and gastrocnemius activity in jumping movements comparing the activation patterns of SJ, CMJ, and DJ. The authors found that there was a significantly greater IEMG activity during the eccentric phase of the DJ than the SJ and that the eccentric activity was significantly greater than the concentric activity during the DJ as well. No difference was found between the CMJ and the SJ, however, when comparing SJ and CMJ multiple muscles showed non-significant electrical potentiation. The authors reported a large variation in individual potentiation patterns, which could be addressed by using subjects of similar training backgrounds that all have experience with jumping tasks. These large variations could account for the lack of significant myo-electrical potentiation and serve as further evidence that trained subjects of similar training histories need to be used for research investigating jumping movements.

To address the differences in neural activation in athletes with either power training or endurance training histories, Kyrolainen & Komi (1995) used 10 endurance- and 10 power-trained athletes to investigate the muscular activation patterns during multiple maximal DJs and on a sledge apparatus. The authors utilized an individualization testing method to find each subject's optimum drop jump height with 0.66 ± 0.15 m for the power trained group and 0.55 ± 0.08 m for the endurance trained group and 0.73 ± 0.08 m and 0.63 ± 0.13 m for the sledge jumps respectively (Heikki Kyröläinen & Komi, 1995). In every condition, the power athletes had a significantly higher take-off velocity than that of the endurance group, as well as significantly greater angular velocities at the knee and ankle. In the drop jumps, the power trained group had a significantly greater eccentric/concentric EMG activation ratio than the endurance trained group for all conditions measured, and a higher rate of EMG development during the pre-activation phase (un-reported values) (Heikki Kyröläinen & Komi, 1995). These results further support the idea that subjects trained in power exercises should be used for jumping studies due to dissimilar EMG patterns when compared to endurance trained athletes.

McBride et al. (2008) reported that there was no significant difference between the concentric EMG activity during CMJ and SJ; despite significant increases in jump height, and forces produced during the CMJ. When comparing the CMJ to a DJ, the authors reported significant differences in the pre-activity (0.11± 0.10 vs 0.20 ± 0.11mV) and eccentric activity (0.45 ± 0.17 vs 1.00 ± 0.36mV) in the agonist muscles, respectively (McBride, McCaulley, & Cormie, 2008). They observed no changes in the concentric activity. To further investigate the possible potentiation of the concentric phase, researchers began investigating AE loads and their effects on EMG patterns (Ojasto & Häkkinen, 2009b).

Ojasto & Hakkinen (2009b) used a bench press movement to compare the use of a 70/70 (eccentric/concentric load relative to 1-RM for each phase) 1-RM iso-inertial bench press protocol to multiple AE protocols utilizing 80/70, 90/70 and 100/70 1-RM loading schemes. In the eccentric phase, the anterior deltoid produced significantly greater EMG activity in the 90/70 and 100/70 compared to the 70/70 conditions. The significant difference in muscle activity observed outlines the potential for AE loading as a training protocol and corroborates the earlier findings from elastic energy storage and reutilization studies (Ishikawa et al., 2006; Ojasto & Häkkinen, 2009b).

SSC movements are defined by Komi & Golhoffer (1997) as having three characteristics: a well-timed pre-activation before the eccentric phase of movement, a short and fast eccentric phase, and an immediate transition from eccentric to concentric. A CMJ does not meet these requirements for a fast SSC and therefore should not be used to address SSC enhancement characteristics. It was the goal of this study, however, to not study the validity of CMJ as an SSC exercise and the role reflexes may play in the countermovement jump, but, do AECMJ elicit a change in the muscle activation during the concentric phase when compared to a free CMJ (Komi & Gollhofer, 1997).

Augmented eccentric loading (acute). AE training, which differs from classical concentric/eccentric training, by utilizing a heavier load during the eccentric phase, is a superior training method for producing more favorable chronic adaptations to strength, hypertrophy, and acute performance enhancements (Friedmann-Bette et al., 2010; Ojasto & Häkkinen, 2009b; Sheppard et al., 2008). Studies involving acute measurements have been conducted in both the upper and lower extremities, utilizing both single and multi-joint movements.

In the upper extremities, the bench press has been used repeatedly for both acute and chronic studies. Doan, Newton, Marsit, Triplett-McBride, Koziris, Fry, & Kraemer (2002) investigated the effects of using an AE load on subsequent concentric 1-RM strength in the bench press, using eight moderately trained men with a mean age of 23.9 years old. They used a specially designed weight-releasing device that allows for 105% of their concentric 1-RM to be lowered and 100% of their concentric 1-RM to be raised. When using the AE loading pattern the 1-RM bench scores were significantly increased from a mean value of 97.44 kg during the normal eccentric condition to100.57 kg in the

AE condition (Doan et al., 2002). Although the authors do not provide rates of force development or other pertinent biomechanical measurements, this demonstrates that an AE protocol can produce positive acute enhancements to performance in the bench press. These results are in disagreement with more recent research investigating AE protocols in slightly older men with a mean age of 32.4 ± 4.3 years (Ojasto & Häkkinen, 2009a).

Ojasto & Hakkinen (2009a) conducted a similar experiment to their aforementioned EMG study and investigated effects of different loading ratios (eccentric/concentric) of AE loading and its effects on acute strength, force and power responses. They used a similar weight releasing device for their testing of 11 male physically active subjects. They used three different loading protocols to compare AE training with traditional iso-inertial training, which consisted of: 105/100%, 110/100%, and 120/100% (% referring to % of 1-RM bench press, measured prior to testing). In all conditions tested, the concentric 1-RM decreased significantly.

As well as testing 1-RM strength, Ojasto & Hakkinen (2009) also investigated the effects of AE loading on explosive strength using five different loading protocols, consisting of 50/50, 60/50, 70/50, 80/50 and 90/50 (% of 1-RM used for eccentric/concentric phases). This was to examine effects of augmenting the eccentric phase on concentric power production. They found that the highest peak and mean power were observed in the 77.3 ± 3.2/50% condition; significantly higher than the control 50/50% condition (Ojasto & Häkkinen, 2009a).The disparity observed in strength results is most likely due to the varying testing procedures and difference in subject population. Ojasto & Hakkinen (2009) used an older population that was only “physically active” instead of the moderately trained, younger men in the Doan et al. (2002) study. Superior performance and training adaptations seen in the upper body bench press studies have led to an interest in examining the effects of implementing an AE load on possible lower body performance enhancement (Aboodarda et al., 2013; Friedmann-Bette et al., 2010; Moore et al., 2007; Sheppard et al., 2007).

Applying AE protocols to the lower-body has provided mixed but promising results in regards to performance augmentation acutely. Moore, Weiss, Schilling, Fry, & Li (2007) conducted a study to compare the acute effects of using a spectrum of augmented eccentric loads on force, velocity and power on the concentric phase of a maximal effort jump squat to a traditional iso-inertial jump squat. Thirteen male subjects with at least six months of heavy resistance training experience participated in the study. Following a practice session, the subjects performed squat jumps under four different loading conditions. The first condition was an iso-inertial condition utilizing a load of 30% concentric 1RM for two sets of one maximal repetition, with two minutes of rest between each set. Each of the following three conditions was conducted in the same manner utilizing AE loads of 20, 50, and 80% 1RM (Moore et al., 2007). The loads were applied using a custom weight releasing device similar to the devices used in the upper body studies (Doan et al., 2002). Using the performance variables of force, velocity, and power, no significant difference was seen across the spectrum of augmented eccentric loads. This is contrary to what was reported by earlier rate enhancing studies, upper body studies and a single joint lower body study (Doan et al., 2002; Friedmann-Bette et al., 2010; Ojasto & Häkkinen, 2009a). It has been demonstrated in previous studies investigating rate of loading (SJ vs. CMJ) and its effects on performance are more accurately studied in trained subjects (Guillaume, Phillip, & Tom, 2013; Komi & Bosco, 1978).

Sheppard et al. (2007) used eleven high-performance male volleyball players as subjects, allowing comparison of unloaded block jumps to loaded block jumps in elite jump trained athletes. For the AE condition, a load of 20 kg (10 kg per hand) was used to accentuate the eccentric phase of the block jump. This was done by holding the weight until the transition phase of the jump, at this time the subject drops the weight and begins the concentric phase unloaded (Sheppard et al., 2007). In all subjects, there was a significant increase in vertical displacement, peak force, peak power, and peak velocity, with mean increases of 4.3, 9.4, 3.9, and 3.1%, respectively. These results demonstrated that when subjects are jump trained, the effect of using an AE loading protocol may be more effective and substantial (Moore et al., 2007; Sheppard et al., 2007). Moore et al. (2007) and Sheppard et al. (2007) both used weights to augment the eccentric phase of dynamic movement. Other studies investigating resisted jumping protocols have utilized resistance bands as method for increasing the resistance during the eccentric phase (Aboodarda et al., 2013).

Aboodarda et al. (2013) investigated the effects of elastic resistance on kinetic and kinematic characteristics during AE CMJ when comparing to a free CMJ. They used fifteen trained male subjects, each performing free countermovement jumps and AE jumps with 20 and 30% bodyweight being added via the tensile force of the bands (Aboodarda et al., 2013). Following a warm-up protocol, and a 10-minute recovery, subjects were instructed to perform three maximal CMJ under each condition in randomized order with 2 minutes rest in between trials. During both conditions, free and

AE, the subjects were instructed to keep their hands on the hips. The free CMJ were performed similar to Bobbert et al. (1996), while the AE CMJ was performed in a novel, yet unstandardized method. Tensile bands were attached to the hips using harness and stretched and kept beneath the feet of two research assistants to the side of the subject. They were well practiced at holding the elastic bands under tension and synchronously releasing the tension when the subject approached the bottom of the CMJ (Aboodarda et al., 2013).

Aboodarda et al. (2013) found that the AECMJ 20% and 30% produced significantly greater jump heights, while the AECMJ 30% condition also produced significantly greater: peak power, peak concentric force, peak concentric velocity, net impulse, and normalized rate of force development (Aboodarda et al., 2013). The peak power enhancements seen in the AECMJ 30% condition compared to the free condition were accomplished by the 6.34% higher vertical GRF and a 14.28% greater concentric velocity, which were not seen in the AECMJ 20% condition. The AECMJ 30% conditions ability to produce a 19.07% greater concentric impulse than the free can be explained by the increase in vertical GRF and the 11.42% longer contact time. These results indicate that by applying a downward tensile load during the eccentric phase of a CMJ can enhance the power output, jump height and concentric impulse in trained young males when compared to a free CMJ. This is in agreement with the previous studies and provides further biomechanical evidence into the efficacy of AE training (Doan et al., 2002; Sheppard et al., 2007). Specifically, by providing insight into the kinetic and kinematic characteristics that are crucial to jump performance, this study shows the possible benefits to AE training acutely. The authors suggest that the use of AECMJ with

30% added tensile bodyweight could be of use to elite athletes that have reached peak strength and power-output capabilities (Aboodarda et al., 2013).

Currently, there is a mixture of results associated with AE loading and its effect on acute performance. Though there have been negative or neutral results reported, the positive results appear promising and offer a basis for future research into AE protocols designed to increase acute performance. Specifically, no standard AE protocol has been described and the two studies involving more of a typical jumping movement (Aboodarda et al., 2013; Sheppard et al., 2007) have provided researchers with promising results demanding further attention. Studies investigating AE have not been limited to acute effects and multiple chronic studies have been conducted. Though the current study was investigating acute effects of AE loading, it was considered important to review the literature that has already investigated the use of AE protocols during training programs in a chronic manner (Friedmann-Bette et al., 2010; Sheppard et al., 2008).

Augmented Eccentric loading (chronic). Multiple studies indicating a positive correlation between AE and acute performance enhancement has lead researchers to investigate the chronic effects of an AE protocol (Brandenburg & Docherty, 2002; Friedmann-Bette et al., 2010; Sheppard et al., 2008). Brandenburg & Docherty (2002) conducted a 9-week training study comparing the strength and neuromuscular adaptations for 18 trained college-aged male subjects, in one of two groups, dynamic constant external resistance (DCER) or dynamic augmented external resistance (DAER). The DCER group performed 4 sets of preacher curls and supine elbow extension at an intensity of 75% 1-RM. The DAER group performed 3 sets of the same concentric intensity but used an intensity of 110-120% 1-RM for the eccentric phase of the curl and elbow extension. In both programs, the frequency was two times per week for the first two weeks and 3 weeks for the remaining 7 weeks. To account for adaptations during the program, the load was adjusted when the average number of repetitions per set during a training session exceeded ten. One flaw to their design, however, was the lack of automated weight adjustment, potentially causing a delay between eccentric and concentric phases, thus possibly inhibiting performance by increasing the amortization phase and wasting stored elastic energy.

Before and after completion of training, they measured muscle CSA and specific tension, with strength being assessed before, after weeks three and six, and nine (Brandenburg & Docherty, 2002). Strength adaptations for the programs were comparable in the flexor muscle group but more favorable strength adaptations occurred in the extensor muscle group with the DAER training protocol. DCER training resulted in a significant increase in concentric 1-RM of flexors and extensors, with increases of 11 and 15% respectively. DAER on the other hand led to a more modest flexor gain of 9% but a larger extensor gain of 24%. When comparing week 9 DAER 1-RM of the elbow flexors to DCER 1-RM of the elbow flexors, DAER was significantly greater. When comparing CSA pre and post training, neither training group produced significant increases in muscle CSA. When comparing the specific tension results, the flexors in both group increased significantly by 9% and the extensors increased 13% in the DCER group and 22% in the DAER group. The difference between the specific tension for the DAER and DCER groups was not significant but does represent a better improvement by the DAER group. The results indicate that although both training protocols elicited positive adaptations the DAER or AE group produced greater adaptations in multiple measurements, which is consistent with other upper body studies (Friedmann-Bette et al., 2010).

Friedmann-Bette et al. (2010) conducted a 6-week training study to compare the effects of using classical isoinertial training (CON/ECC) to AE training (CON/ECC+) on the extensors of the leg using unilateral leg-extension exercise. The leg extensions were performed on either a traditional leg extension machine, or for the AE group, on a custom computer-driven device allowing for augmentation of the eccentric phase. All of the 25 subjects were male athletes with a strength training background. Both the AE training and the classical training program induced significant positive anabolic adaptations measured by CSA, with increases of 5.8 ± 4.3 cm^2 for AE group and 8.0 ± 6.5 cm^2 in the CON/ECC group. Both treatments also produced significant increases in 1-RM strength. They differed, however, in their ability to influence the subject's maximal vertical squat jump. The AE group significantly increased their jump height while the classical group had no change (Friedmann-Bette et al., 2010).

In addition to functional testing, Friedmann-Bette et al. (2010) used biopsies from the vastus lateralis to measure the steady-state levels of 48 anabolic marker mRNAs and fiber type distribution to compare the AE training with classical CON/ECC training. Among the 48 different mRNA marker transcripts tested, gains in MHC IIB and the androgen receptor mRNAs were significantly different between AE and CON/ECC, with the AE group displaying an increase while no change was observed in the CON/ECC group. Lactate dehydrogenase enzyme (LDH) mRNA's also appeared to be preferentially up-regulated by the AE training program resulting in significant increases in both LDH A and LDH B, as well as MCT 4 (lactate transporter), while the CON/ECC group only caused a significant change to the LDH B mRNA (Friedmann-Bette et al., 2010). Fiber type distribution was measured by ATPase staining, and localization of MHC isoform mRNAs using situ hybridization (Friedmann-Bette et al., 2010). Percentage of fiber type distribution was unchanged in both groups, but the AE group showed a statistically significant increase in the fiber CSA of the type IIx fiber which was not seen in the CON/ECC training group. These results, as well as the results of the mRNA marker testing, demonstrate that AE may offer a superior method for training to elicit greater strength and performance adaptations in athletes competing in sports where success is determined by their capacity for explosive strength (Friedmann-Bette et al., 2010). This preferential adaptation seen with AE in the aforementioned study is corroborated by earlier research comparing an AE training program to a control training program (Sheppard et al., 2008).

Sheppard et al. (2008) investigated the effects of a 5 week training protocol using AE jumps on peak force, peak velocity, peak power, and jump displacement. The AE training group significantly increased their displacement by 0.053 ± 0.027 m representing an 11% increase with a magnitude of effect d =1.00. Results also indicate significant increases in power (1083 ± 1183 W) and peak velocity. In contrast, the control group did not exhibit any significant increases in measured variables. In fact, they showed non-significant decreases in peak power, peak velocity, and jump displacement, with a slight non-significant increase in peak force of 52.52 ± 107.2 N. When compared to the control group, the AE training group showed significantly greater results than the control group in displacement, peak velocity and peak power. As this study was conducted with high-performance volleyball athletes (n=16), it supports the notion that AE may be of value to high performance athletes seeking further positive performance adaptations (Sheppard et al., 2008).

Summary

With regards to AE training, multiple mechanisms have been proposed to explain the acute performance increases seen in two of the studies in the literature. It is currently thought that the four primary mechanisms are: an increase in elastic energy storage and utilization, augmented SSC (neural) activation, increased pre-load applied to the muscles during the eccentric phase causing changes in contractile machinery, and passive force development such as Ca^{2+} mediated alterations to titin or other sarcomeric proteins (Moore & Schilling, 2005; Morgan & Proske, 1997; Rassier, 2012) Although these are reasonable proposals for mechanisms to explain the enhancements seen with AE training, it is noted that there is currently no consensus on the underlying mechanism for the acute performance enhancement seen with AE protocols. There are no studies investigating AveIEMG during the concentric phase following the application of an AE protocol in a jumping movement. Results from the proposed investigation may provide further insight into the mechanism involved in the performance enhancements observed in previous studies (Aboodarda et al., 2013; Sheppard et al., 2007). Elastic energy is thought to be the primary contributor to the increases in performance, and EMG analysis from this study may provide further empirical data to support or contradict this (Bobbert et al., 1996b; Ishikawa et al., 2006; Moran & Wallace, 2007)

Chapter III:

Methods

Introduction

The purpose of this experiment was to examine the effect of augmenting the eccentric phase of a CMJ with approximately 30% of the subject's BW. This study was conducted to investigate differences in performance measurements during the countermovement jump by analyzing: pre-load, PPO, jump height, modified RSI, as well as Average IEMG for the VL and MG. This investigation may provide further support for using augmented eccentric (AE) training protocols and may also elucidate further insight into the possible mechanisms of performance enhancement.

Description of Study Population

The subjects were 12 females of college age who were recruited from the Western Washington University NCAA Division II Women's Volleyball team. Subjects were excluded if any lower extremity or low back injuries occurred within the last six months.

Design of Study

The design is a cross-over, controlled, randomized sequence study. Subjects performed both the treatment and control condition in an alternated order, with a flip of a coin deciding the first condition.

Data Collection Procedures

Instrumentation. After signing informed consent, subjects were given a brief five minute introduction to augmented eccentric jumps. Upon completion of the introduction, subjects were instructed to perform the standardized warm up procedure described.

Following the warm up, subjects were fitted with the electronic-goniometer to be used for separating the EMG signals into eccentric and concentric phases for later analysis of the concentric phase. For surface EMG and joint-angle assessment, the Noraxon Desktop DTS (Direct Transmission system) (Noraxon, Scottsdale, AZ) system was used to collect muscle activation and electro-goniometer data at a sampling rate of 1500Hz. Disposable Noraxon dual electrodes (Noraxon, Scottsdale, AZ) Ag/AgCl surface electrodes were placed on the muscle bellies of the subject's vastus lateralis and medial gastrocnemius, in-line with the primary muscle fiber directions. All muscle locations were determined based on previous recommendations (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The inter-electrode distance was 2.0 cm. Before placing the electrodes, the subject was required to shave the respective areas and then clean with an alcohol wipe to reduce skin impedance of the myo-electrical signal. The SG series twin axis electro-goniometer (Biometrics Ltd., Ladysmith, VA) was placed on the lateral portion of the right knee, and was used to record flexion and extension during all trials.

In addition to the EMG and kinematic data, kinetic and kinematic data was also collected. An AMTI® (Advanced Mechanical Technology, Inc., Watertown, MA) OR6-6 force platform was used for collection of kinetic data at a sampling rate of 1200Hz. Recording of kinematic data was done with a high speed Casio® camera (Casio Computer Co., LTD., Shibuya-ku, Tokyo, Japan) sampling at 420Hz. The camera was positioned on a tri-pod oriented perpendicularly to the sagittal plane of the subject during the jumping trials. A meter stick was placed in the frame to be used as a distance reference for MaxTRAQ®.

Measurement Techniques and Procedures. Data collection was performed in one session per subject. Clothing and footwear used for the study was not controlled; however, the subjects were required to wear athletic/training clothing and footwear.

The use of a combination general and specific warm up was utilized per recommendations from the literature (Burkett, Phillips, & Ziuraitis, 2005; Fletcher, 2013). The general warm up consisted of: 3 minutes of treadmill jogging at 5 miles per hour, followed by 1 set of 10 lunge to knee hugs, high knees (15 yards), and power skips (15 yards). The specific warm up was then conducted and consisted of 10 bodyweight squats with a resistance band placed approximately 5 cm above the knee joint, and glute-bridges performed (10 repetitions per leg) on an exercise mat. Rest periods of 30 seconds were given between each warm up exercise with 5 minutes of rest given at the end of the warm up. Upon completion of the warm up, subjects were allowed five sub-maximal practice jumps with the AE protocol to familiarize themselves with the testing protocol. At this time, subjects were given instructions that the jump trial would only be accepted if the Sandbells® (Hyperwear, Inc., Ausitn, TX) used for augmenting the eccentric phase (28.98 ± 4.10 % of BW) were dropped before reaching the bottom of the countermovement. To determine that the Sandbells® were dropped prior to commencement of the concentric phase, a research assistant would inspect the high speed videos from the Casio® camera between trials.

After zeroing the force plate, subjects were verbally cued to come onto the force plate, and were then given a “3, 2, 1, Go” countdown; being instructed to begin their countermovement on “go”. Collection of myo-electric, kinematic, and kinetic data were initiated simultaneously on the count of 1 by the primary researcher and the two research assistants. This procedure was repeated until four trials of both BW and AE CMJ's were collected, the sequence being alternated to counteract a fatiguing bias. In between trials, the kinematic data was used to ensure the Sandbells® were dropped prior to the end of the eccentric phase. Due to fatiguing issues no more than 10 trials were conducted for each subject. Throughout the jumping trials, subjects were encouraged verbally to perform maximally, as well as to limit the amount of time spent in transition from eccentric to concentric movement to maximize the usage of elastic energy storage (Wilson & Flanagan, 2008). Rest intervals between trials were 1 minute. During the 1 minute rest period, video data was inspected to ensure that the subject dropped the weight prior to the bottom of the countermovement jump.

Data Processing. Force data was filtered using a 4^{th} order zero-lag butterworth filter built into the AMTI BioAnalysis software. All EMG data collected was EKG reduced using Noraxon MR3 software (Noraxon, Scottsdale, AZ) before being exported for processing using custom LabVIEW® software. An SG series twin axis electro-goniometer (Biometrics Ltd., Ladysmith, VA) was used to separate the eccentric and concentric phases during data processing. Averages for each subject were calculated using Custom LabVIEW® software.

Force plate data was used to calculate peak power output, peak vertical GRF, pre-load, RSI, and jump height. Peak power output was calculated using a previously validated regression equation (Johnson & Bahamonde, 1996). Calculations for jump height were performed using the time of flight relationship due to the reliability and validity of this method (Komi & Bosco, 1978). The electrogoniometer data was used to detect the bottom of the countermovement (peak knee flexion), which was time-synchronized with the force data to calculate pre-load. EMG data was integrated by time and average IEMG (AveIEMG) was calculated for the concentric phase, allowing for comparison of muscle activation during the concentric phase in each condition. RSI was calculated as the jump height divided by the time to take-off. For all measured variables, an average of the 3 trials processed for each subject were calculated and used to calculate and analyze group means.

Statistical Analysis. All statistical analysis was performed using SPSS software version 20 (IBM North America, New York, NY). A paired two-tailed t-test was used to compare the BW CMJ measurements to the AE CMJ for all dependent variables. Specifically pre-load, PPO, jump height, modified RSI, and AveIEMG of the vastus lateralis (VL) and medial gastrocnemius (MG) during the concentric phase were compared. A Bonferroni correction was used to account for multiple t-tests. The alpha level was set at $p < .01$ for all analyses. Effect size was then calculated to assess the magnitude of the AE loading protocol on each measured variable (Vincent, 2005). Effect size was calculated by taking the difference of the condition means and dividing by the standard deviation of the BW CMJ condition. These were interpreted as 0-0.2 being no effect, .2-.49 being small effects, 0.5-0.8 being moderate effects and .8+ being large effects (Vincent, 2005)

Chapter IV:

Results and Discussion

Introduction

The purpose of this study was to investigate the effect of using an augmented eccentric (AE) load during a CMJ on concentric performance. Performance measures analyzed during both the free and AE CMJs were: jump height, AveIEMG of the vastus lateralis and medial gastrocnemius, PPO, pre-load and modified RSI.

Subject Characteristics

Twelve female subjects recruited from Western Washington Universities NCAA Division II volleyball team were used for this study, with their characteristics summarized below in Table 1. Their average age was 20 ± 1 year. The average height was 1.8 ± 0.1 inches, and the average mass was 72.5 ± 5.8 lbs. The average amount of experience playing volleyball competitively (Club/Collegiate) was 8.83 ± 1.40 years.

Table 1.

Subject Characteristics

	Mean	± SD
Subject Age (years)	20.3	1.0
Subject Experience (years)	8.8	1.4
Subject Height (m)	1.8	0.1
Subject Mass (kg)	72.5	5.8
% of BW Utilized For AE CMJ's	29.0	4.1

Results

As seen in Figure 1 and Table 2, there was no significant difference in jump height for the free and augmented CMJ ($t(11) = 1.104$, $p = .293$), with values of 31.5 ± 3.6 cm and 31.8 ± 3.3 cm, respectively. The effect size of AE loading on jump height was small ($r = .316$). No significant difference was observed in pre-load ($t(11) = .527$, $p = .608$), with a small effect size ($r = .157$). Average pre-load was 1428.2 ± 183.7 N during the free as compared to 1451.2 ± 183.3 N during the AE CMJ (Figure 2.). PPO also showed no significant difference between groups ($t(11) = 1.279$, $p = .227$), with values of 2769.3 ± 467.3 W in the free CMJ and 2795 ± 443.7 W in the AE CMJ (Figure 3). The effect of AE loading on PPO was small ($r = .360$). As shown in Figure 4, neither the VL or MG Ave IEMG showed significant differences between free CMJ (0.28 ± 0.11 mV and 0.14 ± 0.04 mV, respectively) and AE CMJ (0.26 ± 0.09 mV and 0.15 ± 0.05 mV, respectively) ($t(11) = 1.868$, p = .089; $t(11) = 2.090$, $p =.089$, respectively). The VL had a small effect size ($r = .491$) and the MG had a moderate effect size ($r = .533$). RSI showed no significant difference between free CMJ (0.34 ± 0.04 m/s) and AE CMJ (0.34 ± 0.04 m/s) ($t(11) = .227$, $p = .825$), with a small effect size ($r = .068$). Results for RSI are displayed in Figure 5.

Table 2.

Mean, standard deviation, and effect size for Jump height, Pre-Load, Peak Power, AveIEMG, and RSI during both Free and AE CMJ.

	Free		AE		
	Mean	± SD	Mean	± SD	Effect Size
Jump Height (cm):	31.52	3.66	31.84	3.34	0.32
Pre-Load (N):	1428.21	183.68	1451.24	183.28	0.16
Peak Power (W):	2769.30	467.32	2795.16	443.70	0.36
VL AveIEMG (mV):	0.28	0.11	0.26	0.10	0.49
MG AveIEMG (mV):	0.14	0.04	0.15	0.05	0.53
RSI (m/s):	0.34	0.03	0.34	0.04	0.07

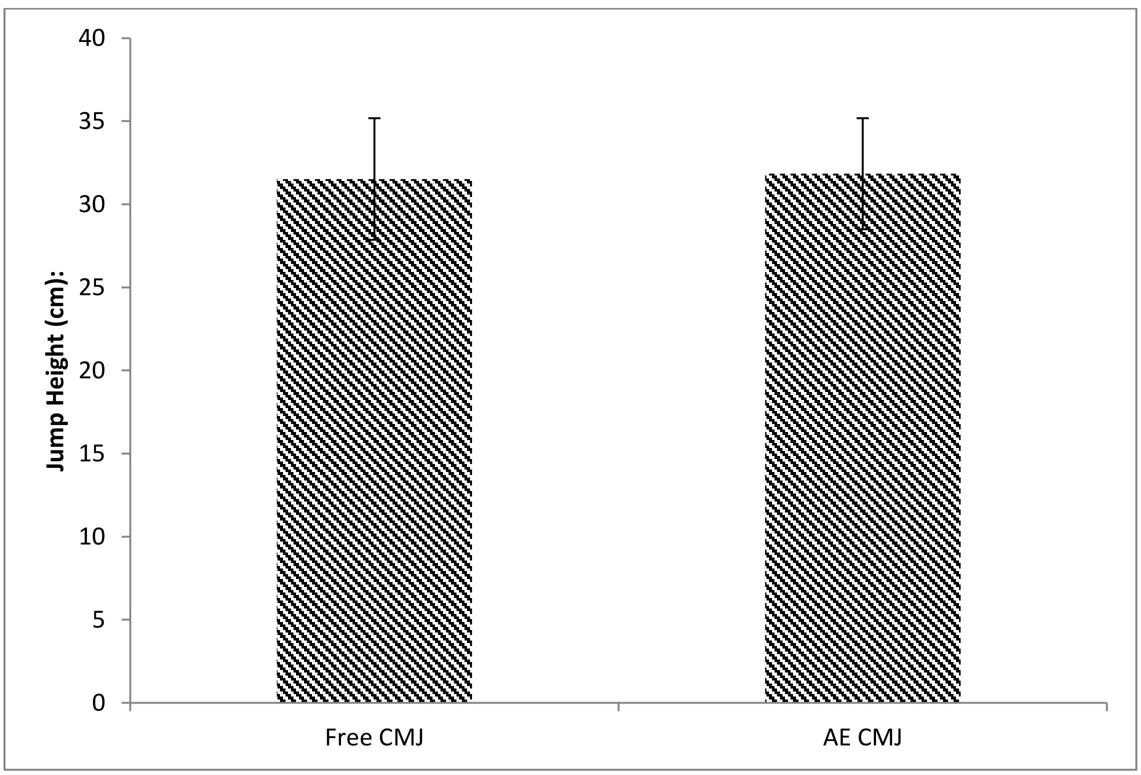

Figure 1. Mean (± SD) jump height during both the free and AE CMJ .

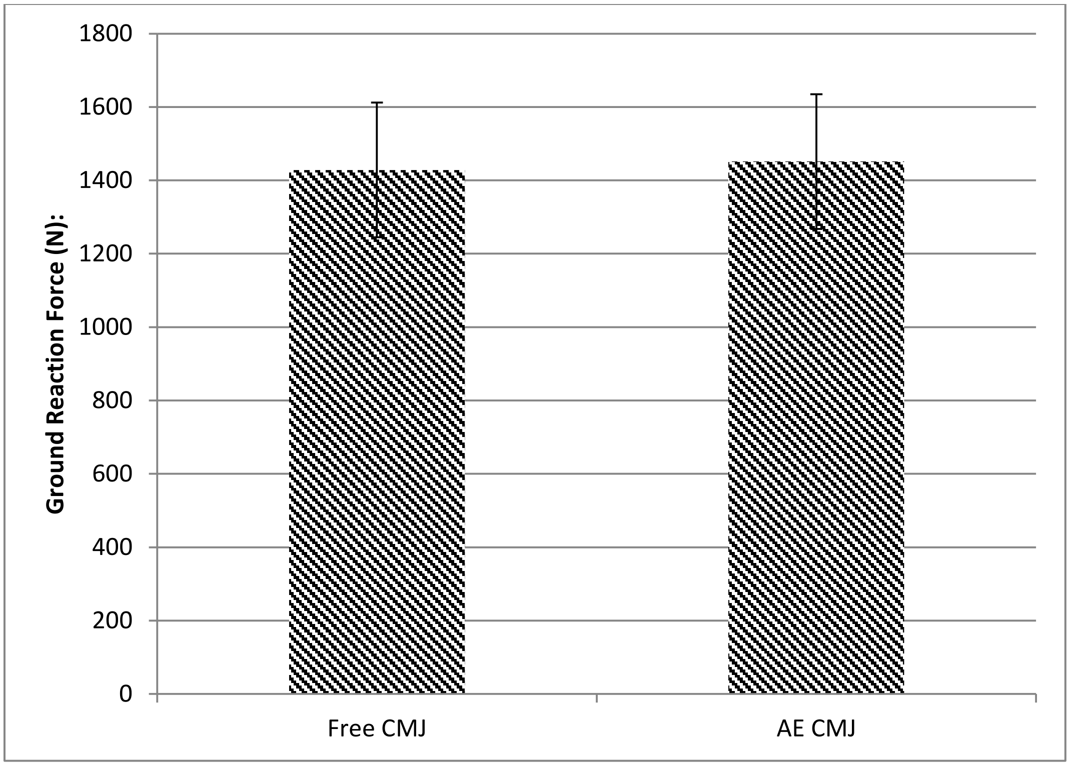

Figure 2. Mean (± SD) pre-load during both the free and AE CMJ.

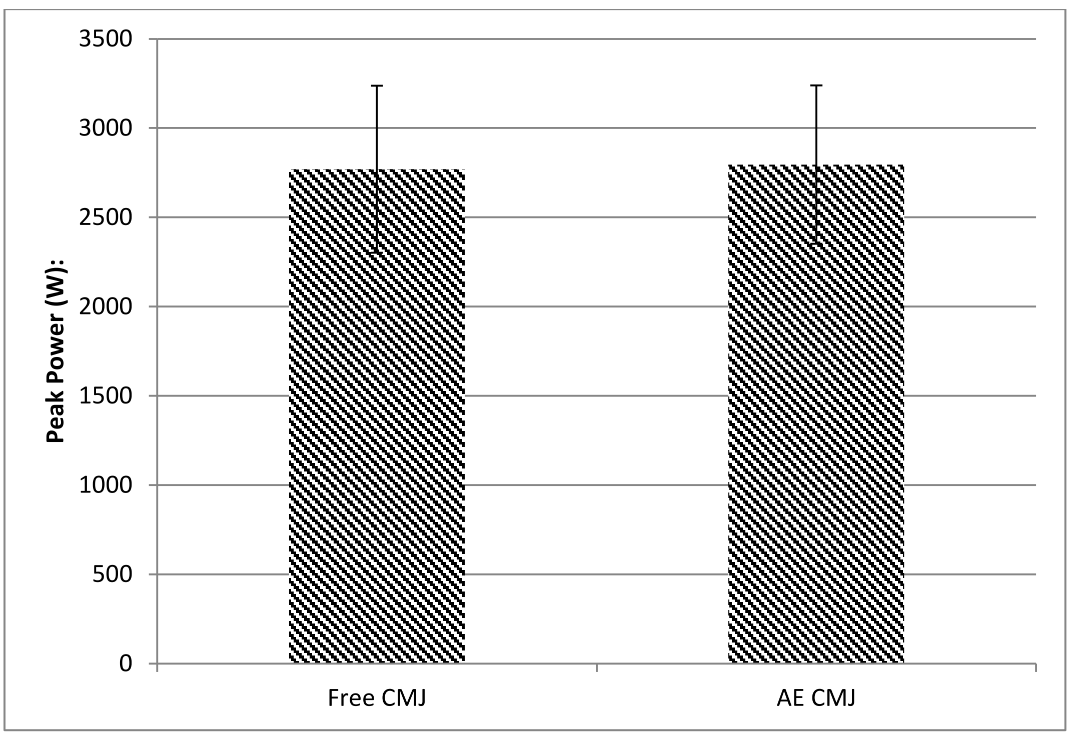

Figure 3. Mean (± SD) peak power during both the free and AE CMJ.

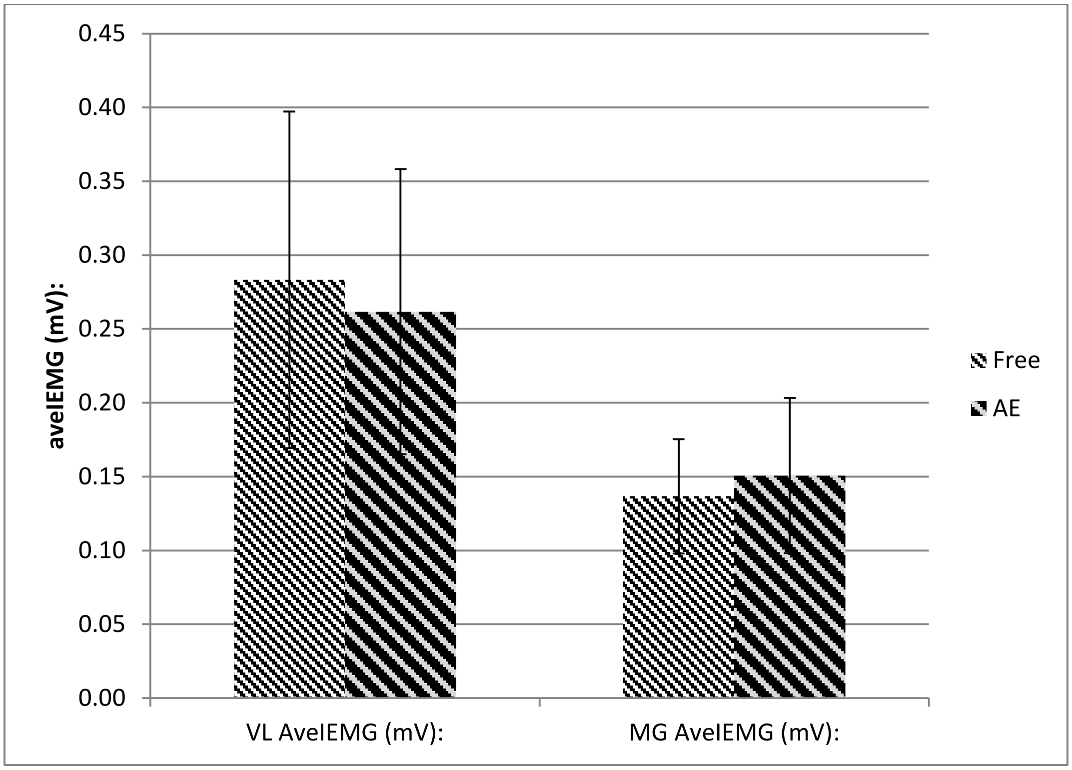

Figure 4. Mean (± SD) AveIEMG of both the VL and MG during free and AE CMJ.

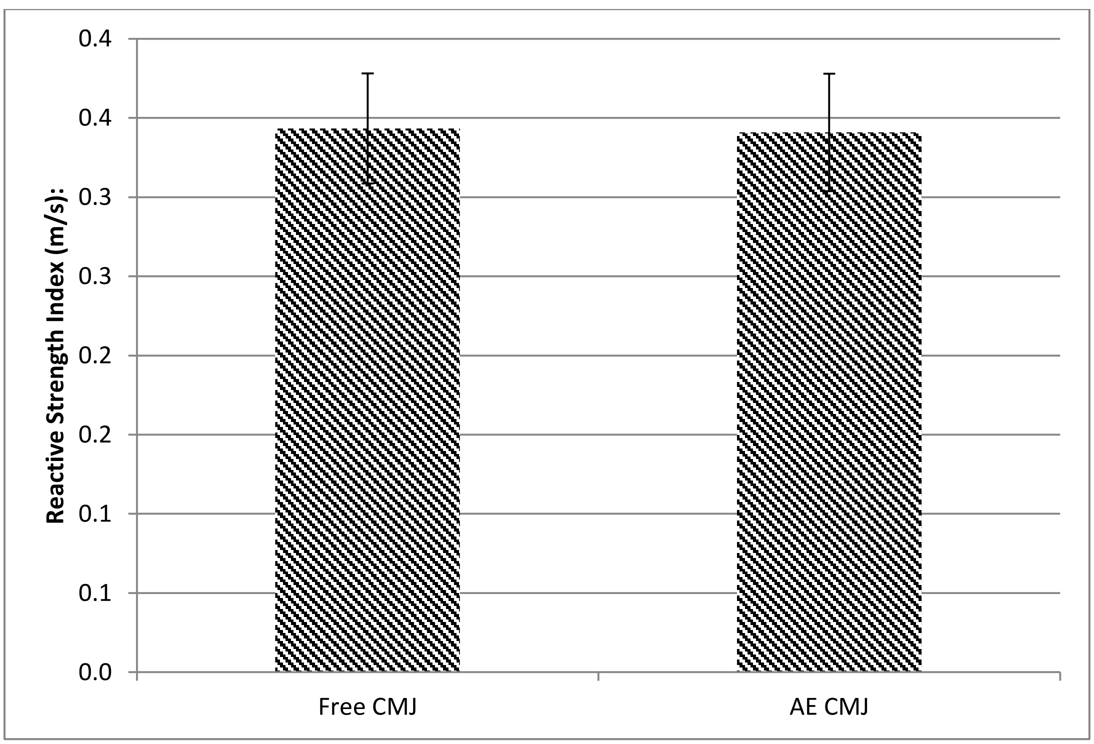

Figure 5. Mean (± SD) modified RSI during Free and AE CMJ.

Discussion

The purpose of this study was to examine the acute effect of AE loading on jumping performance in NCAA division II volleyball players. The augmenting protocol involved the subjects using an average of 28.9 ± 4.10% of their bodyweight for augmentation of the eccentric phase. Subjects held the weight during the eccentric portion of the CMJ, releasing it before reaching the bottom of the countermovement, and immediately performing a powerful concentric jump. Due to the influence of arms on jumping performance, the subjects were instructed to use a similar arm position as the augmented jumps during the free condition. This AE loading protocol was developed to potentiate jump performance acutely by allowing for the induction of previously hypothesized mechanisms: muscle activity potentiation, increased pre-load, an increase in elastic energy storage and utilization, as well as the likely alterations to contractile machinery (Bobbert, Gerritsen, Litjens, & Van Soest, 1996; Cornachione & Rassier, 2012; Moore & Schilling, 2005; Sheppard, Newton, & McGuigan, 2007). The null hypothesis of the study was that the augmented condition would produce no changes in performance during the concentric phase of the jump as measured by: jump height, pre-load, PPO, modified RSI, and the AveIEMG of the vastus lateralis and medial gastrocnemius. Statistical analysis revealed no significant difference between conditions for any of the measured variables when comparing the augmented to the free CMJ.

Our results of no significant difference contradict findings from the only other AE study to measure pre-load (Aboodarda et al., 2013). Aboodarda et al. (2013) found significantly greater pre-load in the AE condition (+30% BW) when compared to the free CMJ, with values of 1773.87 ± 377.88 and 1585.45 ± 333.60N, respectively. As well as pre-load, mean jump height also showed no significant difference between free CMJ and AE CMJ. These results differ from two of the three studies in the literature specifically investigating AE protocols in jumping, however, they are supported by the only other study using recreationally strength trained athletes (Aboodarda, Yusof, Abu Osman, Thompson, & Mokhtar, 2013; Moore, Weiss, Schilling, Fry, & Li, 2007; Sheppard et al., 2007).

Moore et al., (2007) observed no significant differences in the jump squat displacement in recreationally strength trained subjects when using multiple AE conditions, compared to a control group that used isoinertial loads. Sheppard et al. (2007) used high-performance male volleyball players to investigate AE loading and jump performance. They found significant improvements in jump height during the AE jumps (50.5 ± 0.1 cm) as compared to the bodyweight jumps (48.4 ± 0.1 cm).These findings were later supported by Aboodarda et al. (2013) who observed significant increases in jump height during AE jumps (0.42 ± 0.21 m) when compared to bodyweight jumps (0.38 ± 0.03 m). As well as jump heights, PPO observed in this study were not consistent with other reported in the literature accept the study utilizing subjects with a similar training history (Moore et al., 2007).

Though Moore et al. (2007) has corroborating results, two other studies of the lower extremities contradict the current findings of no significant difference in PPO (Aboodarda et al., 2013; Sheppard et al., 2007). Sheppard et al. (2007) observed significantly increased peak power of 5095.5 ± 1225.4 W during AE block jumps as compared to 4655.9 ± 1034.0 W in the bodyweight block jump condition, which is in agreement with Aboodarda et al (2013) who observed significant increases in peak power during the AE CMJ’s (+30% of BW) when compared to unloaded CMJs, with values of 86.49 ± 43.36 W and 66.41 ± 30.31 W respectively. It should be noted that Aboodarda et al (2013) reported power outputs much lower than those observed in the other studies and may have been due to their use of a different, validated method for calculating peak power (Dugan, Doyle, Humphries, Hasson, & Newton, 2004). Aboodarda et al. (2013) did not specify if they subtracted or included bodyweight in their calculations, and state they calculated peak power as a product of force and velocity using the force near peak velocity. This could account for the drastically different values between our study, theirs, and a recent study on PPO in varying populations (Walsh, Böhm, Butterfield, & Santhosam, 2007). Walsh et al. (2007) reported PPO values of 2,445 ± 486 W for physically active females when performing CMJs with no arm movement. The impulse momentum relationship was utilized for their calculations and support the similar values for PPO observed in our study (Walsh et al., 2007).

Another portion of the null hypothesis that was supported by the results of this study was that the concentric AveIEMG was not significantly different between the AE and free conditions. Due to the non-significant difference between conditions, the small and moderate effect sizes for the VL and MG need to be interpreted with caution. This finding is corroborated by the only other study that examined concentric phase EMG activity during an AE bench press, where no significant difference was observed between conditions (Ojasto & Häkkinen, 2009a).

The last portion of the hypothesis that was supported by the results was that the modified RSI would not change during the AE condition when compared to the free condition. RSI indicates an individual’s ability to quickly transition from the eccentric to concentric phase(Ball & Zanetti, 2012; Ebben & Petushek, 2010; Flanagan, Ebben, & Jensen, 2008). This study was the first to use RSI as a measure to compare AE loading to bodyweight CMJs. Typically, RSI is used in DJ evaluation, with the modified RSI being used for activities where the subject/athlete begins on the ground, with larger values indicating a more reactive subject (Ball & Zanetti, 2012; Ebben & Petushek, 2010; Flanagan et al., 2008). The importance of no significant difference in modified RSI when adding an external load of 28.9 ± 4.10% is valuable due to the ability to maintain the capacity to quickly transition from the eccentric to concentric phase despite the added external load. This is important because of the relationship between quick transition times and the usage of stored elastic energy (Wilson & Flanagan, 2008). The paucity of research on AE jumping protocols limits the comparison to the results of this study.

The results found in this study are contradictory to multiple studies finding acute enhancements in multiple exercises utilizing an AE protocol in trained male subjects but corroborated by the only other study to examine AE jumping movements with recreationally strength trained subjects (Aboodarda et al., 2013; Doan et al., 2002; Moore et al., 2007; Ojasto & Häkkinen, 2009; Sheppard et al., 2007). This discrepancy between the current results and those in the literature may be attributed to the vastly different methods used, as well as subjects utilized. Aboodarda et al. (2013) used resistance bands to add the 30% of bodyweight resistance to the subject, which differs from our use of inertial load. When using resistance bands, the amount of force applied is non-linear due to the increase or decrease in tension during movement. Further differences in methodology were seen in calculation of jump height. Sheppard et al. (2007) used a linear position transducer to measure jump height, as compared to the use of time of flight to calculate jump height in our study. As well as measuring jump height by a different method, they did not change the load of AE with respect to bodyweight of the subject. In the current study, each subject's bodyweight was used to determine if either a pair of 20lb or 30lb Sandbells® would be used, with an average load of 28.9 ± 4.10% of BW utilized. Aboodarda et al (2013) also used different methods to calculate jump height when augmenting the eccentric phase with a similar load of approximately 30% of BW using elastic bands. Aboodarda et al (2013) utilized a 3D motion capture system to measure displacement of the greater trochanter, and used that displacement as jump height. This method differs from the use of the time of flight, or the use of a linear position transducer which could then result in variance in the jump height calculations.

Both Aboodarada et al. (2013) and Sheppard et al. (2007) used males for their study, with an average age of 22.6 ± 5.3 years and 18.9 ± 2.6 years, respectively, whereas females with an average age of 20.25 ± 0.97 years were used in the current study. As demonstrated by Komi and Bosco (1978), and more recently Guilame et al. (2013), significant differences exist between male and female elite athletes when comparing performance variables during a CMJ. Not only are there significant gender differences but they are also significant sport specific differences in jump height, movement time and concentric force (Guillaume, Phillip, & Tom, 2013). Volleyball athletes had significantly lower jump heights and concentric force when compared to basketball, football and baseball athletes (Guillaume et al., 2013). Though no significant difference was found in our study between conditions, the maintenance of performance when augmenting the eccentric phase, without a significant change in concentric EMG activity does help guide research for further identification of a possible performance enhancing mechanism that could account for the maintenance of performance seen in our study, and the performance enhancements seen in males in two other studies (Aboodarda et al., 2013; Sheppard et al., 2007).

Multiple researchers have demonstrated increases in RFE during multi joint exercises (Hahn, Seiberl, Schmidt, Schweizer, & Schwirtz, 2010; Seiberl, Paternoster, Achatz, Schwirtz, & Hahn, 2013; Shim & Garner, 2012). In one study utilizing multi-joint lower extremity movement, increases in extensor force and torque of up to 22% were observed following stretch when compared to the isometric condition (Seiberl et al., 2013). This increase in intensity provided by the stretch in their study, as well as the increase in intensity in our study provided by the AE load may allow for superior Ca^{2+}-mediated changes to titin at the sarcomeric level, as well as increases in elastic energy storage in the tendinous-tissue (TT) (Ishikawa, Komi, Finni, & Kuitunen, 2006). Ishikwa et al (2006) demonstrated in male subjects, that with increasing intensity during the eccentric phase of unilateral sledge jumps, the tendinous-tissue (TT) would elongate more while the contractile apparatus would remain quasi isometric. This elongation of the TT that occurs while the contractile portion stays quasi isometric would allow for the exploitation of the viscoelastic properties of the fascial tissues and increased work to be done during the eccentric phase (Bobbert et al., 1996; Moran & Wallace, 2007). An increase in work during the eccentric phase is ideal, due to the ability of the body to then have an increased force at the beginning of the weaker concentric phase (Bobbert et al., 1996; Moran & Wallace, 2007). This increase in work could then lead to the increased force output observed at the end of the eccentric phase (pre-load) by Aboodarda et al. (2013) and may be explained by findings from an inverse dynamics study of increasing intensity on jump performance (Ishikawa et al., 2006; Moran & Wallace, 2007). Moran and Wallace (2007) found that with increasing eccentric intensity (CMJ<DJ), there was a significant increase in the hip joint moment at the beginning of the concentric phase as well as significant increases in total work performed. This increase in joint moment combined with total work resulted in significantly greater jump performance in the DJ than the CMJ and highlights the importance of adding intensity to the eccentric phase to take advantage of SSC style movements (Finni, Ikegaw, Lepola, & Komi, 2001; Moran & Wallace, 2007).

Based on the results observed, using an AE protocol did not produce enhanced acute jump performance in female NCAA division II volleyball players, as shown by no significant difference between conditions in all measured variables. This is of importance because the subjects were able to maintain their jumping performance despite having an extra load of 28.9 ± 4.10% of BW added to the eccentric phase of the CMJ. This not only shows that the subjects were able to maintain performance with an increased eccentric intensity, but they also did it without any significant concentric EMG potentiation, despite a moderate effect of the AE loading on medial gastrocnemius AveIEMG. This suggests that the mechanisms behind enhancements for increased performance observed in other studies following stretch with increasing intensity may rely more heavily on elastic energy storage re-utilization, passive force enhancement, and contractile machinery alterations (Aboodarda et al., 2013; Bobbert et al., 1996b; Rassier, 2012; Sheppard et al., 2007). This ability to maintain performance is highlighted by the superior results observed in chronic studies comparing AE to traditional constant resistance training (Friedmann-Bette et al., 2010; Sheppard et al., 2008)

The results from this study demonstrate the ability of the subjects to accommodate the additional eccentric intensity, while maintaining performance. This ability to maintain performance may prove advantageous when used chronically in a training program when compared to traditional constant resistance exercises. Friedmann-bette et al. (2010) found that a 6-week training program utilizing AE loading for knee extension tasks resulted in significantly increased jump squat height when compared to traditional constant resistance exercise. This significant increase in jump height following an AE training protocol is in agreement with Sheppard et al. (2008) who observed a significant increase in jump displacement (11%) following a 5-week AE protocol. In comparison, the control group using BW jumps in place of AE, showed no significant changes (-2%) in jump height (Sheppard et al., 2008). The results reported from our study of no significant differences between the AE and free CMJ with small to moderate effect sizes, combined with these significant increases observed with chronic application suggest that the use of AE protocols in strength and conditioning programs may be warranted but may not be ideal for NCAA division II volleyball players at enhancing performance.

Summary

AE loading did not significantly enhance the performance during a countermovement jump in NCAA division II female volleyball players. These results are contradictory to recent literature using males as test subjects or when applying the AE load using resistance bands but supported the only other study that used recreationally strength trained subjects during an AE jumping task (Aboodarda et al., 2013; Moore et al., 2007; Ojasto & Häkkinen, 2009a; Sheppard et al., 2007). The discrepancies between the data from this study and the studies observing performance enhancement may be related to sex of the subjects, training history of the subjects, and methodological differences may account for these inconclusive results (Friedmann-Bette et al., 2010; Guillaume et al., 2013; Sheppard et al., 2008, 2007; Walsh et al., 2007). This study did provide empirical data to help further support a mechanism for AE enhancement reported in the literature due to no significant differences in muscle activation during the concentric phase. This suggests a higher reliance on the storage and utilization of elastic energy and passive force enhancement mechanisms to maintain performance during the AE CMJ (Bobbert et al., 1996b; Moore & Schilling, 2005; Rassier, 2012). The inconclusive nature of the results require more exploration to ascertain a conclusive mechanism or mechanisms that will explain the maintenance of performance in the current study, as well as the performance enhancement observed in the literature.

Chapter V

Summary, Conclusions, and Recommendations

Summary

Augmented eccentric (AE) training is a novel training method and literature published in recent years highlights the possible importance of being able to acutely enhance performance during multi-joint movements (Aboodarda et al., 2013; Doan et al., 2002; Friedmann-Bette et al., 2010; Moore & Schilling, 2005; Sheppard et al., 2007). These increases in performance are thought to be made possible by multiple mechanisms including increases in elastic energy storage and utilization, increased SSC reflex contribution, and an increase in the pre-load applied to the muscles during the eccentric phase (related to increased time for force development), as well as altered mechanical structures in the contractile element (Bobbert et al., 1996b; Rassier, 2012).

This study examined the effect that loading 28.9 ± 4.10% of BW to the eccentric phase of a CMJ would have on select performance measures. If one can develop more force, and store more energy during the eccentric phase by performing more negative work, one can increase the jump height during the concentric phase (Aboodarda et al., 2013; Bobbert et al., 1996b; Moran & Wallace, 2007). The ability to handle the AE loading and increase performance may be based on the training level of the subject and possibly gender (Guillaume et al., 2013; Heikki Kyröläinen & Komi, 1995; Walsh et al., 2007).

The use of AE loading did not significantly increase jumping performance in the present study, it did not decrease performance either. This observation demonstrates the ability of the subjects to handle an eccentric load while maintaining performance output and suggests AE loading may be a viable training method to increase intensity without decreasing performance. This contention has been supported by the superior adaptations associated with AE protocols when compared to traditional constant resistance exercise in training studies (Brandenburg & Docherty, 2002; Friedmann-Bette et al., 2010; Sheppard et al., 2008).

Conclusions

Augmented eccentric (AE) loading did not result in an increase in performance in NCAA division II female volleyball players when analyzing: jump height, pre-load, concentric AveIEMG, modified RSI or PPO. The similar performance observed during both a free and AE CMJ may actually highlight an important aspect of the use of AE implementation into strength and conditioning programs. In having no difference, the performance of the jumpers was not inhibited by loading the eccentric phase with 28.9 ± 4.10% of bodyweight. In multiple studies of chronic AE loading, significantly greater adaptations were made when compared to traditional constant resistance exercise (Friedmann-Bette et al., 2010; Sheppard et al., 2008). This is partially supported by this finding of no significant difference between AE and free CMJ performance. No significant decrease in performance suggests that with time AE could possibly result in superior adaptations than traditional constant resistance exercise (Friedmann-Bette et al., 2010; Sheppard et al., 2008).

Recommendations

Future Research. The mechanism for enhanced performance seen in AE protocols in the literature is still under debate, and more research is needed in this area. Due to the lack of significant differences being observed in the present study between unloaded and AE CMJ for the variables measured, and the inconsistent nature of the results in the literature, further investigation of AE protocols and jump performance is warranted (Doan et al., 2002; Moore et al., 2007; Ojasto & Häkkinen, 2009a; Sheppard et al., 2008, 2007). Ideally, the use of a synchronized force plate, EMG and kinematic system could provide valid measures of force output, muscle activation (neural input), and varying kinematic measures. It would also be of interest to conduct an inverse dynamics study of the AE protocol to investigate any alterations to joint reaction forces and torques occurring at the ankle, knee, and hip joints during an AE CMJ as compared to a free CMJ. A thorough understanding of the joint reaction forces and torques produced at the hip, knee, and ankle may provide researchers with more insight into the mechanisms of the performance enhancement seen in the literature (Bobbert et al., 1996b; Moran & Wallace, 2007).

It is recommended in future research investigating AE loading on jump performance that groups be created for subjects depending on relative strength in the back squat, as back squat strength has a high correlation to jumping performance (Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). This contention is supported by some of the subjects in the present study showing an increase in jumping performance measures in AE when explored individually, and is presented in Table 4 in appendix F. It is also recommended that an in-vivo measurement of muscle-tendon unit length of the knee extensors, and ankle plantarflexors during a single-joint or multi-joint AE protocol be conducted so as to possibly elucidate a more definite mechanism for AE enhancement seen in the literature (Aboodarda et al., 2013; Ojasto & Häkkinen, 2009a; Sheppard et al., 2007). It may also be helpful to use a computer model to simulate the effect of augmented eccentric loads on different systems with the ability to manipulate many parameters without the need of live subjects (Bobbert et al., 1996b; Campbell et al., 2011).

Practical Applications. Increasing an athlete's vertical jump performance is usually a primary focus of a strength and conditioning program (Kraemer & Looney, 2012)**.** Though no significant results of augmenting the eccentric portion of the CMJ with an external load were found in the present study, individual responses of some of the subjects, as well as results from the literature indicate a possible benefit of using AE protocols (Aboodarda et al., 2013; Sheppard et al., 2007). This possible benefit to using an external load to augment the eccentric phase has major implications for the practical application of AE loading protocols. The eccentric phases of dynamic exercises are under-loaded due to the limiting concentric strength of the subject. This can be explained by the force velocity curve, which states that an eccentric muscle action can produce more force than a concentric muscle action at the same velocity (Kraemer & Looney, 2012).

If subjects/clients can add greater load to the stronger eccentric phase and increase their ability to generate force and perform more work, before reducing the load during the concentric phase and maintain performance, the potential for superior adaptations are evident (Friedmann-Bette et al., 2010; Sheppard et al., 2008).

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Appendix A

<u>Human Subjects Activity Review</u>

1. What is your research question, or the specific hypothesis?

The null hypothesis is that there will be no difference in concentric rate of force development, pre-load (force developed by the muscles), peak concentric power-output, jump height, or concentric IEMG of the vastus lateralis or medial gastrocnemius between the bodyweight countermovement jump and the augmented eccentric countermovement jump.

2. What are the potential benefits of the proposed research to the field?

Frequently, during athletic events or activities of daily living, movement of the skeleton is accomplished primarily via the combined contributions of isometric, concentric and eccentric muscle actions (Moore & Schilling, 2005). Explosive activities usually rely on the enhancement of movement via a rapid pre-stretch or countermovement (Takarada et al., 1997). When a movement couples an eccentric action with a concentric action, it is termed a stretch shortening cycle (SSC) activity and, as demonstrated by multiple studies, results in an augmentation of concentric performance when compared to pure concentric movement (Aboodarda et al., 2013; Bobbert et al., 1996a; Fukashiro & Komi, 1987; Moran & Wallace, 2007). This pre-stretch can result in increased force production, greater power outputs, and increases in concentric work (Bobbert et al., 1996a; J. B. Cronin et al., 2001; Moran & Wallace, 2007). Understanding the patterns of kinetic and kinematic characteristics of the lower extremity are vital to understanding of the movement, and for optimization of training programs designed to elicit positive training performance enhancement (Aboodarda et al., 2013; Earp et al., 2011; McMahon et al., 2012; Moore & Schilling, 2005).

Mechanisms by which the countermovement can increase performance are still being debated, but are currently thought to include: increases in elastic energy storage and utilization, increased SSC reflex contribution, and an increase in the pre-load applied to the muscles during the eccentric phase (related to increased time for force development), as well as altered mechanical structures in the contractile element (Bobbert et al., 1996a; Bosco & Viitasalo, 1982; J. B. Cronin et al., 2001; T Finni et al., 2001; P. V. Komi & Bosco, 1978; Moore & Schilling, 2005; D. E. Rassier, 2012). Typical training to induce positive adaptations to the aforementioned aspects in athletes involves the implementation of plyometrics and traditional isoinertial explosive exercises (Cormie et al., 2011). Recent evidence suggests that the use of augmented eccentric protocols may offer a more efficient method for producing adaptations favoring explosive performance (Friedmann-Bette et al., 2010).

Unfortunately, typical dynamic constant external resistance training, under-loads the eccentric phase of movement to accommodate the force-limiting concentric phase, and in turn, maximal adaptations for performance are being limited (Brandenburg & Docherty, 2002; Moore & Schilling, 2005). A recently developed training method that utilizes the eccentric intensity dependent characteristics, and has been gaining popularity, is the use of augmented eccentric (AE) training protocols (Aboodarda et al., 2013; Friedmann-Bette et al., 2010; Godard et al., 1998; Moore et al., 2007; Sheppard et al., 2008). This was defined by Moore, Weiss, Schilling, Fry, and Li (2007) as applying a heavy eccentric load immediately before a relatively lighter concentric load. This technique has been investigated in both the lower and upper extremities.

Although the augmented eccentric protocol was first investigated in the upper body, use of this training protocol has now been applied to the lower body (Aboodarda et al., 2013; Friedmann-Bette et al., 2010; Sheppard et al., 2007). Currently there is a paucity of research for lower extremity studies specifically investigating AE protocols during jumping movements (Aboodarda et al., 2013; Moore et al., 2007; Sheppard et al., 2008, 2007). Due to the mixture of inconclusive results in the literature, this study is aimed at providing a biomechanical analysis of AE and bodyweight (BW) countermovement jumps (CMJ), to investigate the acute effects that AE loading has on specific kinetic, kinematic, and myo-electrical characteristics.

3. What are the potential benefits, if any, of the proposed research to the subjects?

Upon completion of this study subjects will know their maximal jump height with bodyweight and using an augmented eccentric protocol. The information that will be provided in a jump summary which can be used to help design training programs to address deficiencies in their jumping pattern or to accentuate positive movement patterns that are already present.

4. Answer a), then answer either b) or c) as appropriate.

a. Describe how you will identify the subject population, and how you will contact key individuals who will allow you access to that subject population or database.

The population sample will consist of women from the WWU varsity volleyball team and male and females from the WWU Track & Field team. . A form requesting permission to contact the athletes will be given to and signed by the head Volleyball coach and the head Track & Field coach before the researcher contacts the athletes. It is understood that all subjects participate in physical training year round. Athletes will be instructed to continue their normal training (including resistance training, conditioning, and sports specific practice), except during the day of testing.

b. Describe how you will recruit a sample from your subject population, including possible use of compensation, and the number of subjects to be recruited.

For this study, 20 women and 10 men will be recruited to participate. The men will be recruited from the track and field team and the women will be recruited from both the WWU Volleyball and WWU Track & field teams. Inclusion for this study demands that subjects be free of any musculoskeletal or neurological impairment or injury. Athletes who participate in this study will not be compensated for their participation.

OR

c. Describe how you will access preexisting data about the subjects.

N/A

5. Briefly describe the research methodology. Attach copies of all test instruments/questionnaires that will be used.

Instrumentation:

After signing informed consent, subjects will be given a brief 5 minute introduction to augmented eccentric jumps. Upon completion of the introduction, subjects will be instructed to perform the standardized warm up procedure. The subject will then be instrumented with retro-reflective markers to improve the accuracy of digitization of video files. Markers will be placed on the greater trochanter (hip), lateral femoral epicondyle (knee), and the lateral malleolus (ankle) of the right leg. Digitization of the markers will provide kinematic data and will be analyzed using MaxTRAQ® (Innovision Systems, Inc., Columbiaville, MI) software. Also fitted to the right leg at this time will be the elctro-goniometer to be used for separating the EMG signals into eccentric and concentric phases.

Recording of kinematic data was done with a high speed Casio® camera (Casio Computer Co., LTD., Shibuya-ku, Tokyo, Japan) sampling at 210Hz. The camera was positioned on a tri-pod oriented perpendicularly to the sagittal plane of the subject while they were performing their jumping trials. A meter stick was placed in the frame to be used as a distance reference.

For surface EMG and joint-angle assessment, the Noraxon Desktop DTS (Direct Transmission system) (Noraxon, Scottsdale, AZ) system will be used to collect muscle activation and electro-goniometer data at a sampling rate of 1500Hz. Disposable Trace 1 (NIKOMED, Huntington Valley, PA) Ag/AgCl surface electrodes will be placed on the muscle bellies of the subject's vastus lateralis, and medial gastrocnemius, in-line with the primary muscle fiber directions. All muscle locations were determined based on previous recommendations (Hermens et al., 2000). The inter-electrode distance is approximately 2.5 cm. Before placing the electrodes, the subject will be required to shave the respective areas and then clean with an alcohol wipe to reduce skin impedance of the myo-electrical signal. Electro-goniometer will be placed on the lateral portion of the right knee.

An AMTI® (Advanced Mechanical Technology, Inc., Watertown, MA) OR6-6 force platform will be used for collection of kinetic data at a sampling at 1200Hz. Custom LabVIEW® (National Instruments, Austin, TX, USA) software will be used to synchronize the force and EMG data.

Measurement techniques and testing procedures:

Data collection was performed in one session per subject. Clothing and Footwear used for the study will not be controlled for; however, the subjects will be required to wear athletic/training clothing and footwear. Subjects were asked to refrain from alcohol and intense activity in the 24 hours prior to testing, as well as caffeine on the day of testing.

The use of a combination general and specific warm up was utilized per recommendations from the literature (Burkett et al., 2005; Fletcher, 2013). The general warm up will consist of: 3 minutes of treadmill jogging at 5 miles per hour, followed by 1 set of 10 lunge to knee hugs, high knees (15 yards), and power skips (15 yards). The specific warm up will then be conducted and will consist of 10 bodyweight squats with a resistance band placed approximately 5cm above the knee joint, and glute-bridges performed (10/leg) on an exercise mat. Rest periods of 1 minute were given between each warm up exercise with 5 minutes of rest given at the end of the warm up. Upon completion of the warm up, subjects will be allowed 5 sub-maximal practice jumps with the AE protocol to familiarize themselves with the testing protocol. At this time, subjects will be given instructions that the jump trial will only be accepted if the weight in the hands (approx. 20-30% of bodyweight) is dropped before reaching the bottom of the countermovement. A custom built Sandbell® catching device was constructed to give feedback to the subjects allowing for drop of the sandbell’s before the bottom of the countermovement.

After completion of warm-up and familiarization, subjects will then be outfitted with the retroreflective markers. After zeroing the force plate, subjects will be verbally cued to come onto the force plate and collection of myo-electric data and kinetic data will be initiated simultaneously using custom LabVIEW® software, while the kinematic data will be initiated manually by a research assistant. Subjects will then be verbally given a “3, 2, 1, Go” countdown and instructed to begin their countermovement on go. This procedure will be repeated until three trials of both bodyweight and augmented eccentric countermovement jumps (AECMJ) are collected, the sequence being randomized via random sequence generator to counteract a fatiguing bias. Due to fatiguing issues, no more than 10 trials will be conducted for each subject. Throughout the jumping trials, subjects will be encouraged verbally to perform maximally as well as limit the amount of time spent in transition from eccentric to concentric movement to maximize the usage of elastic energy storage (Wilson & Flanagan, 2008). Rest intervals between trials will be 1 minute. During the 1 minute rest period, video data was inspected to ensure that the subject dropped the weight prior to the bottom of the countermovement jump.

6. **Give specific examples (with literature citations) for the use of your test instruments/questionnaires, or similar ones, in previous similar studies in your field.**

Using force plates to measure jump height and other kinetic variables has been conducted by multiple researchers using multiple methods. Sheppard et al. (2007) used a force plate in combination with a linear position transducer to measure jump height and power output; both devices sampling at 200 Hz. Sheppard et al. (2008) used similar methods as their earlier study when examining a more long term effect of training with augmented eccentric protocols. Aboodarda et al. (2013) used a force plate (Kistler Instruments Inc., Winterther, Switzerland) and a high speed motion capture system (Vicon MX-F20) to measure peak power and jump height. Their force plate was sampling at 1000 Hz and the high speed motion capture system was sampling at 250 Hz. The PEHR department at Western Washington University uses MaxTRAQ® motion analysis software (Innovision Systems, Inc., Columbiaville, MI) in the Biomechanics (Kinesiology 311) course to analyze high speed videos. Since the MaxTRAQ® motion analysis software is readily available and very accurate, it was chosen for the current study. The Biomechanics lab at WWU is also outfitted with an AMTI® (Advanced Mechanical Technology, Inc., Watertown, MA) OR6-6 force platform was used for collection of kinetic data at a sampling at 1200Hz.

7. **Describe how your study design is appropriate to examine your question or specific hypothesis. Include a description of controls used, if any.**

This study is a single group repeated measures design to analyze the effect of loading the eccentric phase of a countermovement jump with approximately20-30% of the subject's bodyweight. Thirty volunteers will participate in the study. Augmented eccentric countermovement jump measurements will be compared to each subject's bodyweight countermovement jump measurements. This study will also employ t-tests and confidence intervals to compare means of the bodyweight countermovement jump values to the augmented eccentric countermovement jump values.

This study design is appropriate to examine the specific hypothesis, investigating the effect of loading the eccentric phase of a countermovement jump and its effect on jump height, concentric rate of force development, EMG activity, pre-load, and peak power output. This study will examine any differences if there are any between the augmented eccentric condition to the bodyweight countermovement condition.

8. **Give specific examples (with literature citations) for the use of your study design, or similar ones, in previous similar studies in your field.**

There is currently a paucity of research in this field but a few studies have employed similar protocols using a repeated measures design to examine the effect of loading the eccentric phase of a countermovement jump (Aboodarda et al., 2013;

Sheppard et al., 2008, 2007). Measuring jump height during the bodyweight condition and comparing a subjects jump height during the augmented eccentric condition requires a repeated measures design.

9. Describe the potential risks to the human subjects involved.

When conducting any physical activity there are risks of muscle, tendon, ligament, or spinal injury present. Loading the eccentric phase of a countermovement jump is an unnatural movement and may result in injuries due to unfamiliarity with the movement.

10. If the research involves potential risks, describe the safeguards that will be used to minimize such risks.

To ensure safety of subjects, an introduction to the movements utilized will be conducted. The warm –up and jumping trials will be monitored extensively by multiple lab assistants to ensure proper form and safe jumping mechanics. To reduce the chance of fatigue resulting in an injury, rest periods are given to allow for recovery. Also, to minimize the risk of the weights used to augment the eccentric phase, Sandbells® will be used to limit the danger of a dumbbell or weight landing beneath the subject while he/she is jumping.

11. Describe how you will address privacy and /or confidentiality.

Any and all data collected will be kept completely confidential and will be stored and analyzed by subject number only. Only the primary researcher will have access to the records.

12. If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), please attach a clearance letter from an administrator from your research site indicating that you have been given permission to conduct this research. For pre-kindergarten to grade 12 level schools, an administrator (e.g. principal or higher) should issue the permission. For post-secondary level schools the class instructor may grant permission. For Western Washington University, this requirement of a clearance letter is waived if you are recruiting subjects from a scheduled class. If youa re recruiting subjects from a campus group (not a class) at Western Washington University, you are required to obtain a clearance letter from a leader or coordinator of the group.

13. If your research involves the use of schools (pre-kindergarten to university level)or other organizations (e.g., community clubs, companies), and you plan to take still or video pictures as part of your research, please complete

a) To d) below:

a. Who have you contacted at the school district or organization involved, to determine the policy on the use of photography in the school or organization?

The executive directors of the select athletic teams at WWU that will be used in this study have all been contacted. None of the organizations have policies against the use of photography or videotaping.

b. Explain how your research plan conforms to the policy on the use of photography in the school or organization.

All subjects will sign the attached "permission to videotape" form prior to participation in the study.

c. Attach a copy of the school district or organization policy on the use of photography at the schools or organization.

N/A

d. Explain how you will ensure that the only people recorded in your pictures will be the ones that have signed a consent form.

A signed "permission to videotape" form will be obtained before every testing session. Without permission to videotape, the subjects will not be able to participate in the study. See Next page.

In addition, please attach the following information:

1. A bibliography relevant to the subject matter of the proposed research.

See below

2. A copy of the informed consent form (a checklist is attached for you to use as a guide).

See below

3. A current curriculum vitae.

See below

4. **A copy of the certificate of completion for Human Subjects Training from the online human subjects training module, for each person involved in the research who will have any contact with the subjects or their data.**

See below

5. **If your subjects are required to turn in a physical clearance from priot to participation include a copy of the blank form.**

N/A

Appendix B

PERMISSION FORM TO CONTACT THE ATHLETES FOR TESTING (WWU)

Letter of permission:

As the head coach of the Western Washington University women's volleyball team, I,

____________________________ , approve James Matson's thesis research on the WWU varsity volleyball team. This testing will include jump height testing using an augmented eccentric protocol (utilizing sandbells® to augment the eccentric phase of the jump). The testing will involve multiple trials, no more than ten and will be conducted in one session.

____________________________ ____________________________

Coach's Name (printed) Date

____

Coach's Signature

Appendix C

INFORMED CONSENT FOR EXERCISE TESTING

You are invited to participate in a research study conducted by James Matson, from the department of Physical Education, Health, and Recreation at the Western Washington University. This study involves research on augmented eccentric protocols for jumping movements designed to elicit acute performance enhancement in the countermovement jump. Augmented eccentrics may be defined as applying a heavy eccentric load immediately before a relatively lighter concentric load. Countermovement jumps are a powerful dynamic activity that relies on the performance augmentation produced during coupled eccentric and concentric activities which is termed a stretch shortening cycle. The purpose of this research is to investigate the acute effect of loading the eccentric phase of a countermovement jump on: jump height, concentric rate of force development, pre-load, peak power output and EMG activity in two muscles of the lower extremities. Due to the potential fatiguing effect from conducting multiple trials, rest periods will be given after each trial to ensure recovery and maximal effort during each following trial.

Given your participation you will meet for one testing session in the biomechanics lab at Western Washington University. During this session it is vital to adhere to the following expectations:

You will be required to wear athletic/training clothing and footwear. You will also be asked to refrain from alcohol and intense activity in the 24 hours prior to testing, as well as caffeine on the day of testing. You will be given a brief 5-10 minute introduction to augmented eccentric jumps. Upon completion of the introduction, you will be instructed to perform the standardized warm up procedure. A combination general and specific warm up was utilized per recommendations from the literature. The general warm up will consist of: 3 minutes of treadmill jogging at 5 miles per hour, followed by 1 set of 10 lunge to knee hugs, high knees (15 yards), and power skips (15 yards). The specific warm up will include: 10 bodyweight squats with a resistance band placed approximately 5cm above the knee-joint, and glute-bridges performed (10/leg) on an exercise mat. Rest periods of 1 minute will be given between each warm up exercise, with 5 minutes of rest given at the end of the warm up. Upon completion of the warm up, you will be instructed to perform 5 sub-maximal practice jumps with the AE protocol to familiarize yourself with the testing protocol because the jump trial will only be accepted if the weight in the hands (approx. 20-30% of bodyweight) is dropped before reaching the bottom of the countermovement.

Upon completion of the warm-up and the practice jumps, you will be instrumented with retro-reflective markers to improve the accuracy of digitization of video files. These video files will be used to ensure that the weight was dropped before the bottom of the countermovement and for further data analysis. Small markers will be placed on the greater trochanter (hip), lateral femoral epicondyle (knee), and the lateral malleolus (ankle) of the right leg. Also fitted at this time was the electro-goniometer to be used for separating the EMG signals into eccentric and concentric phases. The goniometer will also be attached to the right leg. For surface EMG assessment disposable electrodes will be placed on the muscle bellies of the vastus lateralis and medial gastrocnemius. Prior to placement of these electrodes, you will be required to shave the small area needed for placement and clean the area with an alcohol wipe. This is done to improve the signal of the muscle activity that is measured by the EMG.

Following the warm up and instrumentation, you will begin the jumping trials. You will be verbally cued to come onto the force plate and collection of myo-electric data (EMG) and kinetic (force) data will be initiated simultaneously using custom LabVIEW® software, while the kinematic (video) data will be initiated manually by a research assistant. You will then verbally be given a “3, 2, 1, Go” countdown and will be instructed to begin your countermovement on go. This procedure will be repeated until three trials of both bodyweight and augmented eccentric countermovement jumps (AECMJ) are collected. The sequence of bodyweight or countermovement will be randomized via random sequence generator to counteract a fatiguing bias. Due to fatiguing issues, no more than 10 trials will be conducted for each subject. Throughout the jumping trials, you will be encouraged verbally to perform maximally as well as limit the amount of time spent in transition from lowering yourself to propelling yourself through the jumping movement. Rest intervals between trials will be 1 minute. During the 1 minute rest period, video data will be inspected to ensure that you dropped the weight prior to the bottom of the countermovement jump; indicating a successful trial that can be used for further analysis.

When conducting any physical activity there are risks of muscle, tendon, ligament, or spinal injury present. Loading the eccentric phase of a countermovement jump is an unnatural movement and may result in injuries due to unfamiliarity with the movement. You may withdraw from participation in this study at any time, without penalty.

The benefits of this research are that, upon completion of this study you will know your maximal jump height under both bodyweight and augmented eccentric conditions. The information will be provided in a jump summary which can be used to help design training programs to address deficiencies in your jumping pattern or to accentuate positive movement patterns that are already present. The results of this study may aid in future research.

Any questions you may have regarding the study procedures will be answered by the primary researcher (James Matson) who can be contacted at matsonj4@students.wwu.edu or 360-269-1323. Any questions about your rights as a research subject should be directed to Janai Symons, the WWU Research Compliance Officer (RCO), 360-650-3082. If any injury or adverse effect of this research is experienced you should contact James Matson, or the HPA.

Any and all data collected will be kept completely confidential and will be stored and analyzed by subject number only. Only the primary researcher will have access to your records.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you have received a copy of this form, and that you are not waiving any legal claims, rights or remedies. Signing of this document also ensures that you, the participant, are older than 18 years of age and do not require authorization from a legal parent/guardian.

_______________________________ _______________________________

Participant Name (printed) Date

____

Participant Signature

Appendix D

PERMISSION FORM TO VIDEOTAPE

Permission to video record the jumping trials are required for participation in this study, to ensure the release of the Sandbells® prior to the beginning of the concentric phase. I, ______________ hereby give the investigator, James Matson, permission to photograph and/or videotape my participation in this study.

______________________________ ______________________________

Participant Name (printed) Date

____

Participant Signature

Appendix E

Research Protocol Checklist and Data Logging

Augmented Eccentric Data Collection: Checklist & Data Logging			
Date:		Subject Number:	
Time(Begun/Completed):		Height (in):	
Age (yrs):		Weight (N):	
Injury History:			
Amount of Experience:			
Collection Prep:			
Consent Signed:	Yes / No	Video Consent Signed:	Yes / No
Explanation of Test:	Yes / No	Subject on Master Sheet:	Yes / No
Questions:	Yes / No	Video Sheets Prepared:	Yes / No
Shaved and Ready for Electrodes:	Yes / No	Proper Clothing & Footwear:	Yes / No
Room Set Up:			
High Speed Camera:	Yes / No	Lighting:	Yes / No
Meter Stick:	Yes / No	Markers & Tape:	Yes / No
Assistants Prepared:	Yes / No	Sandbells Ready:	Yes / No
Warm Up:			
Treadmill Jogging (3 min. @ 5mph)	Yes / No	BW Squats w/ band (10)	Yes / No
Lunge to KH (5/leg)	Yes / No	Glute Bridges (10/leg)	Yes / No
High Knees (15 yards)	Yes / No	5 sub-max AE jumps	Yes / No
Power Skips (15 yards)	Yes / No	Technique Instruction:	Yes / No
5 minutes rest and Equipment Implementation:			
Double Check Set-up:	Yes / No	Assistant Ready at Camera:	Yes / No
Stop watch:	Yes / No	Clipboard w/ Subject/Trial #'s:	Yes / No
Reflective Markers on R Leg:	Yes / No	**Goniometer on R Leg and reading properly:**	Yes / No
Force Plate Zereod:	Yes / No	**Electrodes on R Leg & reading properly:**	Yes / No
Collection of Trials:			
Randomized Sequence:	Yes / No	Instrumentation correct:	Yes / No
Commands for Subject (trials):	1) Grab Specified Sandbells 2) Upon taring the FP ask subject to step on Holding Sandbells **(remind them to be as stable as possible)** 3)Make sure EMG, FP, & Camera are ready to collect 4) Verbally cue the Subject to begin with a 3,2,1, GO Command 5) Subject will begin on Go and Collection of Data will begin on the 2 count 6) Start timer for 1 minute Rest 7) After completion of the jump, check the video to ensure proper technique (did the sandbells get dropped in time) 8) Check data before de-instrumentation		
Post Data Collection:			
Files For Each Trial Saved Properly:	Yes / No	Files Backed-up:	Yes / No
Save With Subject #,Trial # & type of Trial:	Yes / No	Save Summary and Raw data from Labview:	Yes / No
Notes:			

Appendix F

Individual Subject Data

Table 3. Individual means and group means, standard deviations, and effect sizes for the Free CMJ.

Free CMJ						
Subject	**Jump Height (cm):**	**Pre-Load (N):**	**Peak Power (W):**	**VL AveIEMG (mV):**	**MG AveIEMG (mV):**	**RSI (m/s):**
1	31.00	1669.63	3072.49	0.26	0.14	0.33
2	29.76	1225.55	2350.18	0.26	0.14	0.36
3	28.03	1457.61	2473.97	0.30	0.13	0.31
4	30.12	1474.85	2860.52	0.62	0.10	0.31
5	38.80	1454.35	3026.71	0.26	0.13	0.42
6	27.35	1197.59	1883.69	0.23	0.19	0.34
7	36.02	1426.85	3010.15	0.22	0.12	0.39
8	33.87	1237.66	2966.82	0.32	0.23	0.35
9	32.17	1295.91	2611.92	0.22	0.14	0.32
10	30.32	1551.74	2928.25	0.22	0.11	0.31
11	26.58	1345.77	2348.03	0.18	0.09	0.32
12	34.24	1801.04	3698.84	0.31	0.12	0.36
Mean:	31.52	1428.21	2769.30	0.28	0.14	0.34
std. dev	3.66	183.68	467.32	0.11	0.04	0.03
std. error	1.06	53.02	134.90	0.03	0.01	0.01

Table 4. Individual means and group means, standard deviations, and effect sizes for the AE CMJ.

AE CMJ						
Subject	**Jump Height (cm):**	**Pre-Load (N):**	**Peak Power (W):**	**VL AveIEMG (mV):**	**MG AveIEMG (mV):**	**RSI (m/s):**
1	32.24	1758.64	3130.44	0.29	0.15	0.29
2	31.35	1282.40	2466.84	0.20	0.17	0.36
3	28.08	1652.39	2498.23	0.34	0.15	0.35
4	30.80	1674.29	2896.05	0.52	0.14	0.35
5	38.12	1206.44	2982.19	0.26	0.11	0.35
6	27.14	1290.79	1970.20	0.20	0.20	0.31
7	36.41	1445.03	3048.42	0.19	0.12	0.40
8	33.69	1297.78	2965.45	0.29	0.29	0.32
9	30.87	1339.25	2494.47	0.23	0.15	0.35
10	30.01	1605.79	2898.87	0.22	0.10	0.27
11	28.78	1361.15	2480.23	0.15	0.12	0.36
12	34.56	1500.95	3710.57	0.25	0.11	0.38
Mean:	31.84	1451.24	2795.16	0.26	0.15	0.34
std. dev	3.34	183.28	443.70	0.10	0.05	0.04
std. error	0.96	52.91	128.08	0.03	0.02	0.01

Appendix G

Statistical Analysis Tables

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Free_Jump_height	31.5219	12	3.65987	1.05651
	AE_Jump_Height	31.8375	12	3.33721	.96337
Pair 2	Free_Preload	1428.2125	12	183.68350	53.02486
	AE_Preload	1451.2417	12	183.27547	52.90707
Pair 3	Free_Peak_power	2769.2975	12	467.31935	134.90348
	AE__Peak_power	2795.1633	12	443.69913	128.08491
Pair 4	Free_VL_AveIEMG	.2833	12	.11396	.03290
	AE_VL_AveIEMG	.2617	12	.09656	.02788
Pair 5	Free_MG_AveIEMG	.1367	12	.03869	.01117
	AE_MG_AveIEMG	.1507	12	.05257	.01518
Pair 6	Free_RSI	.3433	12	.03473	.01003
	AE_RSI	.3408	12	.03704	.01069

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Free_Jump_height & AE_Jump_Height	12	.964	.000
Pair 2	Free_Preload & AE_Preload	12	.660	.019
Pair 3	Free_Peak_power & AE__Peak_power	12	.990	.000
Pair 4	Free_VL_AveIEMG & AE_VL_AveIEMG	12	.940	.000
Pair 5	Free_MG_AveIEMG & AE_MG_AveIEMG	12	.915	.000
Pair 6	Free_RSI & AE_RSI	12	.436	.157

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Free_Jump_height - AE_Jump_Height	-.31559	.99002	.28580	-.94462	.31344	-1.104	11	.293
Pair 2	Free_Preload - AE_Preload	-23.02917	151.26347	43.66600	-119.13739	73.07905	-.527	11	.608
Pair 3	Free_Peak_power - AE__Peak_power	-25.86583	70.06153	20.22502	-70.38080	18.64914	-1.279	11	.227
Pair 4	Free_VL_AveIEMG - AE_VL_AveIEMG	.02167	.04019	.01160	-.00387	.04720	1.868	11	.089
Pair 5	Free_MG_AveIEMG - AE_MG_AveIEMG	-.01401	.02322	.00670	-.02876	.00074	-2.090	11	.061
Pair 6	Free_RSI - AE_RSI	.00250	.03817	.01102	-.02175	.02675	.227	11	.825