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An Investigation of the Relationship Between a Static Jump Protocol and Squat Strength: A
Potential Protocol for Collegiate Strength and Explosive Athlete Monitoring

A thesis
presented to
the faculty of the Department of Exercise and Sport Science
East Tennessee State University

In partial fulfillment
of the requirements for the degree
Master of Arts in Kinesiology, Leisure and Sport Studies
Concentration in Exercise Physiology and Performance

by
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August 2015

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Keywords: static jump, training adaptations, back squat, athlete monitoring

ABSTRACT

An Investigation of the Relationship Between a Static Jump Protocol and Squat Strength: A Potential Protocol for Collegiate Strength and Explosive Athlete Monitoring

by

Cody Taylor Haun

The purpose of this study was to examine the relationship between estimated absolute and relative squat strength and a static jump protocol with potential to provide desirable training adaptation data to practitioners in the field of collegiate strength and conditioning. Forty-one young (20.80 ± 2.44 years), healthy volunteers reported estimated back squat 1RM's based on the most recent training block and completed a static jump protocol. Males ($n=19$, est. 1RM $141.29 \pm 32.02\text{kg}$) and female ($n=22$, est. 1RM $71.56 \pm 19.64\text{kg}$) jump data revealed large to very large correlations between squat strength, mean jump heights of jumps and other calculated variables.

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DEDICATION

This thesis is dedicated first and foremost to my God; by him I live, and move, and have my being (Acts 17:28). I am extremely fortunate to have such an amazing wife that encouraged me throughout this writing process. I also dedicate this to you Courtney, and look forward to encouraging each other in our academic and professional endeavors for many years to come. I love you beyond explanation and am so very thankful for you. I also dedicate this Thesis to my wonderful mother, Marie, who has supported me and loved me beyond my ability to understand and express gratitude for. I simply would not be writing this without your consistent, loving presence in my life and motivating me to work hard throughout my academic career. I thank you so much for all you've done to help me reach this point and love you so very much. I also dedicate this to my late father, Ron, who taught me much about life, study, and becoming a man; I would certainly not be here without him and acknowledge the many wonderful years we had together before his passing. I also dedicate this Thesis to my father-like mentor, Tim. You have played so many important roles to help me reach this point in my life and I thank you for all the words of wisdom you've shared and all of your help along the way. I'm so fortunate to know such a wise, generous person and appreciate your positive influence on me as a young man. Furthermore, I dedicate this to the rest of my family, close friends, and colleagues who have all played key roles in my development as a person and academician; I appreciate all of your help and encouragement throughout this writing process and thank you for tolerating me on long, low-carb days of writing. I would also like to dedicate this thesis to the Sport Scientists before me, and express my gratitude in their provision of quality research and efforts to elucidate truth via scientific investigation.

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CHAPTER 1

INTRODUCTION

Statement of Problem

The nature and goals of collegiate competitive sport in the United States necessitates that athletes are competing in a physiological state permitting them to perform well enough to win competitions and repeat this act throughout a competitive season. This goal necessitates coaches and athletes minimize and ideally eliminate unnecessary fatigue levels resulting from improper training and fatigue management in order to optimize performance at appropriate times to win important competitions and ultimately championships (Bompa & Haff, 2009; Mujika, 2009; Stone, Stone, & Sands, 2007). Strength and explosive athletes in the collegiate setting seek to increase and maintain levels of strength and power throughout different phases of their competitive schedule. Consequently, the creation and implementation of training programs, monitoring methods, and prescriptions of recovery to enhance adaptation have increased markedly in the last 50 years (Bompa & Haff, 2009; Hornsby, 2013; Stone et al., 2007). The above factors have increased the number of investigations and efforts by sport scientists, strength and conditioning coaches, sport coaches and ultimately whole athletic departments at universities to optimize this process in order to give strength and explosive athletes a greater physiological capacity to perform well and, ideally, better than their opponents as success in sport is ultimately driven by winning and losing competitions. This has led to the creation of many training programs and monitoring methods in the collegiate setting that, in some cases, unnecessarily risk the health status of the athlete, cause undue strains on student-athlete schedules, or are simply not as effective as other more evidence-backed programs and monitoring methodology (Stone, Sands, & Stone, 2004).

The need arises for a safe, convenient, valid and reliable monitoring model to assess collegiate strength and explosive athlete adaptations effectively and one that adheres closely to university and National Collegiate Athletic Association (NCAA) policy producing desired data of benefit to the sport scientist, strength and conditioning staff and sport coaches to help optimize performance. In relation to collegiate strength and explosive sport performance, monitoring the training process affords the strength and conditioning professional important abilities. Some of the more prominent abilities are: 1) the ability to control the development of unnecessary amounts of fatigue during different phases of the training plan and competitive season, 2) the ability to adjust training variables appropriately to promote optimal training adaptations and performance preparations (e.g. peaking), and 3) precise monitoring offers an objective lens through which to view training, recovery and coaching interventions for their effectiveness (Banister & Calvert, 1980; Bompa & Haff, 2009; Issurin, 2009; Medvedyev, 1986; Olbrecht, 2000; Sands & McNeal, 2000; Sands & Stone, 2005; Siff, 2004; Smith, 2003; Stone et al., 2007). Logically, the potential to predict and “post-dict” (Sands & McNeal, 2000) various responses to training and, ultimately, competition performance is important for strength and conditioning professionals and sport coaches necessitating monitoring of the training process. Of particular importance to performance in strength and explosive sports, is the monitoring of lower extremity strength. Many authors have reported that lower extremity strength is associated with explosive movements such as sprinting, jumping and changing direction quickly (Barnes et al., 2007; Carlock et al., 2004; Cronin & Hansen, 2005; Israetel, 2013; Kale, Asçi, Bayrak, & Açıkada, 2009; Nimphius, McGuigan, & Newton, 2010; Nuzzo, McBride, Cormie, & McCaulley, 2008; Peterson, Alvar, & Rhea, 2006; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004). For

example, Peterson et al. demonstrated that athletes who were stronger performed better in performance tests seeking to evaluate the ability to change direction (Peterson et al., 2006).

Due to its contribution to explosive movements, lower extremity strength has emerged as a particular focus of testing in the practical setting (Baechle & Earle, 2008). Currently, the one-repetition maximum (1RM) back squat is considered the gold standard for measuring maximum strength in lower extremity musculature in the practical setting (Baechle & Earle, 2008; Bazylar, 2013). However, 1RM back squat testing induces relatively high amounts of fatigue, can consume a large amount of time in the practical setting at the expense of an actual training session or sport practice, and can easily be inaccurately measured. Thus, 1RM testing should be implemented strategically at certain times of the year, and be supplemented with more regular implementation of other tests, such as vertical jumping and the isometric mid thigh pull, that are less fatiguing and less time consuming. Two predominant forms of vertical jump testing, static and countermovement jumps, have been reported to be popularized and integrated into the practical setting for athlete monitoring and testing (Mizuguchi, 2012; Moir, Sanders, Button, & Glaister, 2005; Sams, 2014; Taylor, Chapman, Cronin, Newton, & Gill, 2012). Of the two, the countermovement jump (CMJ) is more common among high level coaches surveyed (Taylor et al., 2012). Interestingly, no consensus existed among the coaches identifying which vertical jump testing methods and variables of said tests were most meaningful (Taylor et al., 2012). While CMJ is more commonly used in monitoring, some static jump (SJ) variables, based on more recent findings, may be somewhat more capable of providing better insight into lower extremity strength and fatigue monitoring (Blache & Monteil, 2013; Byrne & Eston, 2002; Carlock et al., 2004; Gee et al., 2011; Haff et al., 1997; Hoffman et al., 2002; Kraska et al., 2009; Raastad & Hallén, 2000; Robineau, Jouaux, Lacroix, & Babault, 2012; Sams, 2014; Stone et al., 2003).

Stone and colleagues (Stone et al., 2003) investigated relationships between maximum strength and peak power in CMJ and SJ with loads ranging from 0-100% of self-reported squat 1RM. Static jump peak power had larger correlations ($r= 0.75-0.94$) to squat 1RM at every loading condition compared to CMJ ($r= 0.60-0.88$). Other authors have also reported larger correlations between variables of SJ and measures of strength and explosiveness compared to CMJ (Carlock et al., 2004; Haff et al., 2005; Kraska et al., 2009). Carlock and colleagues reported SJ and CMJ variables relationship to squat 1RM in sixty four junior and resident national-level weightlifters. Carlock and colleagues created a ratio by dividing peak power for SJ and CMJ by body mass reported as peak power static jump $\cdot\text{kg}^{-1}$ and peak power countermovement jump $\cdot\text{kg}^{-1}$. Peak power static jump $\cdot\text{kg}^{-1}$ produced a coefficient of 0.42 compared to peak power countermovement jump $\cdot\text{kg}^{-1}$ producing a coefficient of -0.17. Furthermore, when the subject pool was combined ($n= 64$), SJ height produced a larger correlation coefficient with squat 1RM of 0.58 compared to 0.52 for the CMJ trial (Carlock et al., 2004).

Haff and colleagues collected unweighted SJ and CMJ data in eight men with at least two years of training experience in “explosive” exercise (Haff et al., 1997). SJ peak force produced higher correlations than CMJ peak force with isometric rate of force development and isometric peak force, measured by the isometric mid thigh pull. Correlation coefficients were 0.57 between SJ peak force and isometric rate of force development and 0.76 between SJ peak force and isometric peak force vs. 0.44 and 0.53 between these isometric variables and CMJPF. Furthermore, a correlation coefficient was found between vertical displacement (m) in SJ and isometric rate of force development equal to ($r= 0.82$) and a correlation coefficient between isometric peak force and vertical displacement for SJ equal to ($r= 0.56$), compared to the

correlation coefficient produced between CMJ vertical displacement and isometric rate of force development ($r = 0.07$) and the correlation coefficient produced between CMJ vertical displacement and isometric peak force ($r = -0.35$). Furthermore, vertical displacement produced the highest correlations among other SJ variables collected (peak force, rate of force development, peak power) with isometric rate of force development revealing the potential to simply use static jump height in the practical setting to yield insight to the aforementioned mechanical measures. Additionally, SJ vertical displacement produced greater correlation coefficients for all measures (peak force, rate of force development, peak power) in the dynamic pull trials at each load compared to CMJ vertical displacement. Correlation coefficients ranged from 0.47-0.88 between SJ vertical displacement and dynamic pull measures and -0.09 - 0.27 between CMJ vertical displacement and dynamic pull measures. The reported correlations between SJ and measures of strength and explosiveness suggest the possibility that variables of SJ may allow indirect monitoring of changes in squat strength. In practical settings, the use of SJ to monitor could reduce fatigue induced from 1RM squat testing and save time for practices and conditioning activities.

The previously discussed investigations appear to support the idea that SJ height, in both unweighted and weighted conditions, may allow indirect monitoring of changes in squat strength. This investigation was exploratory in nature. The purpose of this investigation was to investigate the relationship between unweighted and weighted static jump variables and estimated back squat 1RMs based on the most recent block of training in young, healthy adults of varying levels of strength in the back squat to potentially provide a protocol practical for use among practitioners in the collegiate strength and conditioning field for monitoring purposes. Many of the subjects were current Division 1 athletes or had recently ended their competitive

career, making this study unique to many studies with similar conceptual underpinnings, but not using athletic populations. The goal of the authors was to further clarify the relationship of unweighted and weighted static jumps with squat strength beyond our current understanding, in order to help make a more evidence-backed decision concerning the researched protocol's integration into the collegiate setting to indirectly monitor squat strength adaptation, specifically.

Operational Definitions

1. countermovement jump (CMJ): A type of vertical jump preceded by eccentric loading (Mizuguchi, 2012; Sams, 2014).
2. fatigue: A reduction in the force generating capabilities of a muscle or group of muscles.
3. rate of force development (RFD): The rate of force development, typically measured from the onset of a movement until 50-250ms range of time, is measured in Newtons per second ($N \cdot s^{-1}$) and considers the change in force divided by the change in time (Bompa & Haff, 2009; Stone, Stone & Sands, 2007).
4. power: The product of force and velocity, also characterized as a work-rate ($P = \text{Force} \times \text{Distance/Time}$).
5. sport performance enhancement group (SPEG): An acronym symbolizing the Sport Performance Enhancement Group. This entails the sport coaches, strength and conditioning staff, and athletic training staff actively involved in the training process of the athlete/s.
6. strength: The ability to generate force. This force, having both a magnitude and direction, is measured in Newtons (N) (Hornsby, 2013; Stone, 2003).

7. static jump (SJ): A type of vertical jump performed from a static squat position without a countermovement (Blache & Monteil, 2013).

8. strength and explosive athlete: A strength and explosive athlete is considered any athlete competing in a sport with a large strength and explosive component. Endurance-based sports, like cross country running, are not considered to have a large strength or power component. Given that relatively low forces and measures of power are repeated at more submaximal levels in a sequential, repetitive manner in endurance sports, and higher forces and measures of power in various strength and explosive sport tasks occur in a more irregular manner in tasks such as collisions with opponents, explosive jumping and throwing implements; a distinction between these categories of sport can be made. A few examples of strength and explosive sports are American football, basketball, baseball, and volleyball.

9. training intensity: Generalized as work per unit of time that training and sport activities are performed. Additionally, regarding weight training, refers to absolute percentages of a maximum attempt or a relative percentage of a best performance in a specific lift (Bompa & Haff, 2009; Hornsby, 2013; Stone et al, 2007).

10. training volume: Generalized as the total quantity of activity performed in training and sport practice. Additionally, regarding weight training, defined as sets x reps x load or sets x reps x load x displacement (Bompa & Haff, 2009; Hornsby, 2013; Stone et al, 2007).

CHAPTER 2

COMPREHENSIVE REVIEW OF THE LITERATURE

The value of a comprehensive athlete monitoring model has been discussed and reviewed extensively by a number of Sport Scientists (Bompa & Haff, 2009; Hornsby, 2013; Medvedyev, 1986; Sands & McNeal, 2000; Smith, 2003; Stone et al., 2007; Taylor, 2012). Some prevailing, more pronounced benefits that a comprehensive strength and explosive athlete monitoring model offer the Sport Performance Enhancement Group-hereafter referred to as SPEG- are, 1) the potential to lower and ideally eliminate unnecessary amounts of fatigue during different phases of the training plan and competitive season to reduce injury potential, 2) provides the opportunity and foresight to adjust training and practice variables and scheduling in a more optimal, systematic fashion to peak at appropriate time rather than somewhat arbitrary, impulsive approaches, and 3) offers an objective lens through which to view training, recovery and coaching interventions for effectiveness. The focus of this Literature Review deals predominantly with point 3, and is concerned with contributing evidence to better understand the importance of monitoring collegiate strength and explosive athletes, understanding what training adaptations are important to monitor in this setting, and investigate approaches to monitor these training adaptations, and practically applicable methods in a college setting. Finally, the author offers an investigation (See Ch. 2) examining the relationship between squat strength and a static jump protocol with a relatively large subject pool of mostly current collegiate strength and explosive athletes to offer a potential monitoring tool for practitioners in the collegiate strength and conditioning setting.

The Importance of Monitoring Collegiate Strength and Explosive Athletes

Much work has been done in this area by Dr. Mike Stone, Professor of Sport and Exercise Science at East Tennessee State University (2005-2015) and former Head Physiologist of the United States Olympic Committee (2002), over the last 35 years. One would be doing great injustice to not first acknowledge his efforts in scientific investigation to optimize the training process via a thorough athlete monitoring model as Dr. Stone has more publications than any other researcher, to the knowledge of the author, pertaining to this subject to date and much of what we know about current periodization modeling originates from his consolidation of ideas from other Sport Scientists. Many references to his work will be made throughout this literature review pertaining to this topic as few American Sport Science studies exist without his name as either a contributing or main author, or multiple citations in other author's work attributed to his investigations. Stone et al. (Stone et al., 2007, p. 182) note that "only comprehensive monitoring offers a means of measuring and then controlling both the planned and unplanned aspects of training." Reasons to monitor collegiate strength and explosive athletes range from simply maintaining a good coach-athlete relationship via athlete feedback from surveying, to invasive testing methods ensuring aimed adaptations to training interventions. A thorough discussion of worthy attributes of a comprehensive athlete monitoring model is beyond the focus of this literature review. However, three main attributes of a strength and explosive athlete monitoring model that entail some of the more minor attributes are the following: 1) By proper monitoring, the SPEG can markedly lower an athlete's risk of injury by properly managing fatigue from training and competition stress, 2) by proper management of fatigue and training stressors, comprehensive monitoring allows the SPEG staff to plan training and aspects of practice and competition scheduling to ,ideally, peak in performance at appropriate times and 3) a

comprehensive athlete monitoring model offers the SPEG staff an objective lens through which to view the effectiveness of training, practice, recovery and coaching interventions (Banister & Calvert, 1980; Bompa & Haff, 2009; Issurin, 2009; Medvedyev, 1986; Olbrecht, 2000; Sands & McNeal, 2000; Sands & Stone, 2005; Siff, 2004; Smith, 2003; Stone et al., 2007).

Reducing Injury Potential via Comprehensive Athlete Monitoring

Arguably, the most important intention of integrating a comprehensive monitoring model is lowering the athletes' risk of injury. Without the athlete being in a physiological state allowing the capacity to perform free of hindering injuries inhibiting completion of necessary sport-specific tasks, the athlete will simply not be able to compete effectively regardless of talent or effort as they simply won't be involved in the competition due to being injured. Authors have demonstrated that both training for and competition in strength and explosive sports induce varying levels of fatigue. Fatigue is an inherent consequence to both training and competition in strength and explosive sport and the failure to manage these levels on behalf of the SPEG staff can be detrimental to the athlete resulting in increases in risk of injury if adequate recovery/adaptation from training and competition stress do not occur (Andersson et al., 2008; Ascensao, Leite, Rebelo, Magalhães, & Magalhães, 2011; Bompa & Haff, 2009; Cormack, Newton, & McGuigan, 2008; Hoffman, Nussle, & Kang, 2003; Medvedyev, 1986; Nicol, Avela, & Komi, 2006; Sands & McNeal, 2000; Smith, 2003; Stone et al., 1991; Stone, O'Bryant, Garhammer, McMillian, & Rozenek, 1982; Stone & O'Bryant, 1987; Stone et al., 2007). As noted by Hornsby (Hornsby, 2013), fatigue can be characterized by the descriptive: acute or chronic. Fatigue effects from training and competition can be further explained by Issurin's model (Issurin, 2009). Issurin characterizes training effects as acute, immediate, cumulative, delayed, and residual (Issurin, 2009). Issurin offers various time frames associated with the

recovery from said stressors associating each type with a given time period for better planning of training and competition. Issurin argues that certain effects from training-induced stressors extend into weeks and months and thus necessitate proper planning of stressors considering more long-term effects on performance of the athlete. Other authors also portray related findings from investigations, stating that recovery from strength and explosive competition alone requires up to 3 or more days in certain cases (Andersson et al., 2008; Cormack et al., 2008; Hoffman et al., 2003). Some physiological mechanisms attributed to fatigue relate to both the central and peripheral nervous systems with various other physiological consequences occurring in the working muscle cells themselves. Physiologic responses post-exercise/post-competition have shown reductions in muscle glycogen (G. G. Haff, Lehmkuhl, McCoy, & Stone, 2003), accumulation of lactic acid (Westerblad, Allen, & Lännergren, 2002), reductions in phosphocreatine (Bogdanis, Nevill, Boobis, & Lakomy, 1996), increases in plasma cortisol levels (Nieman & Pedersen, 1999) and decrements in continued performance capacity (Bompa & Haff, 2009). When these physiological consequences of training and competition occur, rather than the muscles of the athlete producing and absorbing adequate forces in training and competition, much of the stress is shifted to connective tissue, joints and other aspects of the skeletal system increasing the athletes' risk of both minor and severe injury given that the force producing capability is directly related to available energy (Radin, 1986; Yoshikawa et al., 1994). This concept has also been referred to in the more cumulative, chronic stage as overtraining syndrome and is believed to contribute greatly to injuries in competitive strength and explosive athletes (Bompa & Haff, 2009; Smith, 2003; Stone et al., 1991). By managing these stressors with a thorough monitoring model, the SPEG staff gives the athlete a greater

chance of recovering from these inherent consequences and continuing to compete throughout the season and train more intensely.

Tapering and Peaking: Implications for Athlete Monitoring

Tapering and Peaking has been discussed extensively by Mujika (Mujika, 2009) along with other previously mentioned Sport Scientists like Stone, Bompa, Haff, Medvedyev, Issurin, Siff and Verkoshansky (Bompa & Haff, 2009; Issurin, 2009; Medvedyev, 1986; Siff, 2004; Stone et al., 2007). Mujika proposed that it is often not the most “talented” competitor that wins a competition but rather the one who is most prepared or properly “peaked” at the most critical moment (Mujika, 2009). This idea has been propagated by many other well-known sport scientists and is embodied in the “fitness-fatigue paradigm”. This paradigm is a primary conceptual underpinning of the training process with its roots ultimately traced back to Hans Selye’s General Adaptation Syndrome model (Bompa & Haff, 2009; Hornsby, 2013; Kavanaugh, 2014; Selye, 1956; Siff, 2004; Stone, Plisk, & Collins, 2002; Stone et al., 2007). Basically, the concept of tapering and peaking entails lowering an athlete’s training load at proper times to perform better for major competition (Bompa & Haff, 2009; Hornsby, 2013; Mujika, 2009; Stone et al., 2007). Mujika and Padilla (Mujika & Padilla, 2003) note that expected performance gains of approximately 3% can be expected in response to a taper. Greater enhancements of performance of up to 11% in certain cases and positive enhancements in muscular strength and power of up to 25% have been noted in response to proper tapering and peaking by Bompa and Haff (Bompa & Haff, 2009, p. 194). Izquierdo and colleagues reported a taper protocol resulting in 2% increases in back squat and bench press performance (Izquierdo et al., 2007) (Bompa & Haff, 2009, p. 194). As Bompa and Haff also note, the difference between 1st place and 3rd place in the 2004 Athens Olympic Games in weightlifting was 2.21% in

women and 1.73% in men, demonstrating the importance of these small changes in performance leading up to high level competition (Bompa & Haff, 2009, p. 194). The idea of not doing anything too strenuous the week of an important competition can be viewed by most as common sense but the concept of tapering and peaking goes far beyond simply doing less and involves intricate and precise drops in training volume load which relates to changes in training intensity the weeks leading up to said competition (Bompa & Haff, 2009; Mujika, 2009; Stone et al., 2007). As noted by Sands & McNeal, (Sands & McNeal, 2000), there seems to be an optimal window of both training volume and intensity prescriptions during different phases of training when certain performance adaptations are sought. Without closely monitoring training volume load and intensity, and the athlete's response to these prescriptions objectively, a fair question to ask is, "How will a coach know the precise changes in volume and intensity to maintain induced adaptations from previous training but not add significant amounts of fatigue the weeks leading up to competition?". Obviously, this question cannot be objectively answered without close monitoring of training volume load and intensity and the athlete's response to these alterations. The above scientific evidence and discussion demonstrate the importance of monitoring collegiate strength and explosive athletes to properly taper and peak at appropriate times during the annual plan.

Objectively Analyzing the Training Plan

Additional to lowering the risk of injury and allowing the opportunity to peak in performance for important competitions, monitoring the collegiate strength and explosive athlete also affords the SPEG staff the capacity to objectively see if their training, coaching, and recovery interventions are working. The thorough discussion of advanced athlete monitoring models exceed the purpose of this literature review as the intent of other authors has been to

extensively discuss more in-depth, precise methods of monitoring in high-performance athletes (Kellmann, 2010; Sams, 2014; Taylor, 2012). Some of the more prominent, practical monitoring variables of resistance training programs for strength and explosive athletes in the collegiate setting will be discussed in this section to serve the purpose of justifying the importance of monitoring adaptations from resistance training for strength adaptation. The remainder of this section will focus on aspects of the training plan that seem to be worth monitoring and why it's important to be able to view these aspects objectively. Sport leaves little room for subjective opinion in terms of success as it is ultimately driven by the win-loss column. Feeling that a training program is working and subjectively observing gains in performance via in-person experiences mean very little if one isn't able to objectively show clear gains in strength and performance via documented and precisely tracked training variables; especially when referring to the relationship between the Strength and Conditioning Staff and the Head Sport Coach. The chief purpose of the Strength and Conditioning Staff of a strength and explosive sport is to increase strength and derivatives thereof (i.e. measures of power, RFD, etc.) via the implemented training program while also ensuring adequate levels of conditioning for in-competition performance, implied by the title of the occupation. Tracking progress of athletes in their individual training programs is not only important for the reasons stated previously in this review but also allow the strength coach, particularly, to know whether or not the integrated training plan is producing the desired changes in performance characteristics. Certain variables of training programs have emerged as important aspects worth monitoring in the scientific literature and warrant inclusion by practitioners in the field of Sport Science and Strength and Conditioning in the collegiate setting.

As noted by Stone et al. (Stone et al., 2007, p. 184), “training dosage is perhaps the easiest, most logical, and simplest area of monitoring-both general and specific.” Bompa & Haff, (Bompa & Haff, 2009, p. 79), argue that, “Volume is a primary component of training because it is a prerequisite for high technical, tactical, and physical achievement.” Bompa & Haff (Bompa & Haff, 2009, p. 79) propose volume as “the distance covered or the volume load in resistance training (i.e., volume load=sets x repetitions x resistance in kg) and further discuss volume simplistically as the “total quantity of activity performed in training.” As Hornsby (Hornsby, 2013) notes, there are some issues with various studies in their attempt to quantify resistance training volume noting “displacement” must also be considered as anthropometrics are different among different athletes and certain exercises and variations change the displacement of the weight being lifted increasing or decreasing the work; causing actual training volume load to be somewhat difficult to calculate. An extensive review of different definitions of volume load and how to calculate it is beyond the scope of this literature review and the purpose of introducing it as a monitoring tool and considering its implications on adaptation can be accomplished without thoroughly defining it. Simply put, it is important for the SPEG to monitor training volume load in that it provides the necessary stressor to drive various training adaptations sought from resistance training and a “dose-response” relationship exists between resistance training volume load and adaptation (Berger, Harre, & Ritter, 1982; Bompa & Haff, 2009; Olbrecht, 2000; Sands & McNeal, 2000; Schoenfeld, 2010; Stone et al., 2007). Hence, without tracking the dose how can one predict or even “post-dict” the response? (Sands & McNeal, 2000) If the training dose wasn’t accurately tracked then “post-dicting” the response becomes very challenging to the practitioner as a number of different stressors could have caused the given response. Another training variable that has emerged as an important facet to monitor is training intensity. Various

definitions exist in the scientific literature for training intensity. Komi (Komi, 2003) defines intensity in relation to power output or “work per unit of time”, opposing force, or velocity of progression. As noted by Bompa & Haff (Bompa & Haff, 2009), this denotes that the more work the athlete performs per unit of time, the higher the intensity. A more simplistic definition offered by a number of authors can be divided into two terms known as “relative” and “absolute” and further filtered by the author of this literature review as follows: 1) “absolute intensity” can be understood in regard to resistance training programs as an absolute percentage of a best performance, typically a percentage of a 1-repetition-maximum test or a “repetition maximum” (i.e. 5RM) (Kraemer & Fleck, 2007); 2) “relative intensity” can be understood as an intensity scalar for a given training session or specific lift. For example, assume an athlete was prescribed to complete 3 sets of 5 repetitions of the barbell back squat at a relative intensity of 90%. This means that the athlete will select a load or be provided a load range by the SPEG staff that is 90% of an athlete’s actual estimated 5RM during that specific training session. Relative intensity essentially compensates for how “prepared” the athlete is the specific day of training taking into account outside stressors and cumulative fatigue rather than programming a specific absolute intensity assuming the athlete is truly expressing strength reflective of the date of the 1RM test. (Bompa & Haff, 2009; Nàdori, Granek, & Hortobágyi, 1989; Stone et al., 2007). As shown by a number of authors, strength is somewhat variable on different days at different points during training programs of athletes due to fatigue, outside stressors, and various other reasons causing variations in strength levels expressed on a daily basis and relative intensity seems to offer more positive training benefits as absolute percentages assume a 100% relative intensity each training session (Bompa & Haff, 2009; Haff et al., 2008; Hornsby, 2013; Izquierdo et al., 2006; Painter et al., 2012; Stone & O’Byrant, 1987; Stone et al., 2007). As noted by Taylor’s recent review of the

literature, a “valley of fatigue” is necessary to induce different training adaptations and is created by the manipulation of training volume and intensity at different points in the annual plan of an athlete (Taylor, 2012; Taylor et al., 2012). Without precisely tracking training volume load and intensity being completed during athlete’s training sessions, the SPEG staff cannot objectively state which variables of the training program are causing what adaptations and also forfeit the ability to objectively show strength and explosive gains over time.

Although few long-term studies in collegiate strength and explosive sport athletes exist, there are reported benefits in more recent long-term monitoring studies to a properly periodized training program closely monitoring both training volume and intensity. Kavanaugh’s (Kavanaugh, 2014) investigative dissertation work showed enhancements in maximal strength by 44% and vertical jump height by 20-30% in conjunction with volleyball practice in Division I women’s volleyball athletes after about two and a half years of training, offering a unique perspective in long-term athlete monitoring. Some other authors have seen similar results in American football players, men’s and women’s basketball, and women’s gymnastics while long-term monitoring in other collegiate strength and explosive sports are virtually non-existent per the author’s review of the literature (French, 2004; Hoffman, Ratamess, & Kang, 2011; Hunter, 1993; Jacobson, Conchola, Glass, & Thompson, 2013; Miller, White, Kinley, Congleton, & Clark, 2002; Petko, 1997; Stodden & Galitski, 2010). Long-term monitoring studies of weightlifters have also shown benefits of proper periodization modeling closely monitoring training volume load and intensity but, interestingly, were conducted decades earlier with more recent investigations being more short-term in nature and offering little information on long-term phase sequencing and performance enhancement (Bompa & Haff, 2009; Hakkinen, 1985, 1989; Hornsby, 2013; Medvedyev, 1986; Stone et al., 2007). By precisely tracking volume load and

intensity for each and every training session and analyzing loads being used coinciding with various intensity scalars and set/repetition schemes, the ability to see increases in strength and explosive becomes possible. A superior form of monitoring maximum strength adaptation, specifically, is the implementation of maximum strength testing sessions; in that the intent is to assess maximum strength directly rather than indirect estimates using training session data.

Testing various performance characteristics at specific times during the annual plans of athletes can be viewed as a type of athlete monitoring. Strategically placing testing sessions throughout annual plans allows a more valid and reliable assessment of training adaptations and provides updated data for training programming purposes for upcoming blocks of training and feedback to the coach. It also allows athletes to see how they compare to their teammates and normative data in existence for opponents at the same level, or even allows comparison to more elite performers. This warrants the need for testing protocols that will allow accurate assessments of training adaptations. Although other training adaptations have been shown to occur from resistance training of interest to the SPEG staff (e.g. increased peak power, increased RFD, hypertrophy) (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Holtermann, Roeleveld, Engstrom, & Sand, 2007; Winchester et al., 2008), the focus of this literature review deals more with strength adaptation. The following section seeks to define strength specifically in relation to collegiate strength and explosive sport and offers more technical considerations of strength adaptation for practitioners in the field of strength and conditioning/sport science to better “steer” the training/monitoring process.

Strength: Defining Strength in Relation to Collegiate Strength and Explosive Sport

Per his recent review of the literature Hornsby (2013) defines strength as “The ability of the neuromuscular system to produce force. Force is a vector quantity and has a magnitude and direction.” (Hornsby, 2013) The magnitude of strength can be characterized in ranges from 0% to 100% for simplicity sake and understanding (Stone et al., 2007). Hornsby also defines “maximum strength”, separately, as “The maximal voluntary force a muscle or group of muscles can exert under specific conditions. It can be measured concentrically, eccentrically, or statically.” (Hornsby, 2013). These are commonly agreed upon ways of defining strength in relation to the intent of training programs and sport performance (Bompa & Haff, 2009; Israetel, 2013; Stone et al., 2007). Strength is recognized as one determinant of performance in competitive strength and explosive sports, by nature, as athletes’ ability to produce varying levels of force at critical times is required to perform sport-specific tasks superior to their opponents (Stone et al., 2007). Per the suited definitions above, strength shouldn’t only be considered as how much weight one can lift, but rather characterizing strength as an ability to produce force and considering that force production involves both a magnitude and direction are also necessary undertakings in context of performance. Practical observation of strength and explosive sports demonstrates that all strength and explosive sports in the collegiate setting aren’t simply demonstrations of athletes’ abilities to produce consecutive efforts of “Maximum Strength” throughout competitions but rather must be considered to involve varying levels of strength requirements during different sport-specific tasks. Increasing maximum strength has been shown to be important for improving strength and explosive sport tasks like sprinting and jumping and will be discussed in the following section (Strength as a Key Adaptation in Strength and explosive Sports). A more technical analysis of strength and its components will be

discussed in the remainder of this section considering important attributes of strength and the discussion of some of the more prominent physiological mechanisms of strength will follow.

(See Physiologic Mechanisms of Strength Adaptation of this Literature Review)

As noted earlier, strength must not be simply considered to be an absolute amount of weight lifted but is expressed differently and to different extents in strength and explosive sports at different times throughout competition. For instance, a basketball player jumping to pull down an uncontested rebound from a missed shot involves different levels of strength compared to a basketball player attempting to slam dunk a basketball with a defender grabbing his uniform, over an opposing player. This is one example of many others that entails athletes displaying different levels of strength at different points throughout competition to accomplish different tasks. As noted by Israetel, in his recent dissertation discussing the interrelatedness of fitness characteristics for sport performance in Division I athletes, strength is expressed in “all” athletic movements (Israetel, 2013). Israetel goes on to note that “strength results in force production of a given duration, a rate of force development, and a power output.” (Israetel, 2013, p. 23) When discussing the physical mechanisms of strength as an ability, it is important to note the product of strength in relation to strength and explosive sports is force production and force has both a mass component and an acceleration component (Israetel, 2013; Stone et al., 2007). Thus, 1RM testing for strength and explosive sports in the collegiate setting to assess maximum strength alone not including other tests measuring explosiveness and expressions of other performance characteristics don’t provide other pertinent data involving varying levels of strength associated with explosiveness and other performance characteristics. Also noteworthy, force, calculated as the product of mass and acceleration, is a vector quantity yielding both a magnitude and direction and the implementation of various tests of strength should also consider kinetic/kinematic

specificity of the strength assessment to the given sport. This yields credence to the idea that monitoring strength adaptation shouldn't necessarily be limited to 1RM testing in a certain exercise or estimating maximum strength from a repetition maximum test in an exercise (e.g. 5RM) but rather that the testing/monitoring process should offer pertinent data to the SPEG revealing athlete strength behavior with kinetic/kinematic specificity to the given sport (Bompa & Haff, 2009; Stone et al., 2007). For example, it is common to assess 1RM strength in particular exercises in a weight-room setting of certain commonly programmed lifts like the bench press, overhead press, back squat and deadlift (Baechle & Earle, 2008). The kinetic/kinematic specificity of a one-repetition maximum effort overhead press offers little pertinent strength data to the SPEG staff of a soccer team, lacking a triple extension component, and is an uncommon, biomechanically speaking, aspect of in-competition soccer performance. Although the referenced overhead press assessment does offer a reflection of upper body strength in a soccer players, the nature of the exercise and the fatigue generating properties of the assessment might be better replaced with a movement pattern more specific to the sport with conditions that the athlete can express more sport-specific strength, like a clean, back squat or weighted static jump (Sams, 2014). Due to time constraints, funding issues and institutional policy in collegiate settings, certain testing and monitoring protocols aren't possible in many programs and various practical methods that seem to offer more positive data will be discussed in a later section (See Plausibility of Methods in the Collegiate Setting). The above points regarding specificity of testing and monitoring to specific sports led Stone and colleagues (Stone et al., 2007) to conclude, "Choosing a reliable and valid response variable or variables depends on the purpose of the response monitoring, level of invasiveness you can achieve, desired frequency of measurements, financial resources available, and ease of data analyses and

reporting.” (Stone et al., 2007, p. 185). The consideration of the above points are vital to the successful integration of strength monitoring protocols in the collegiate setting and warrant consideration before deciding upon an optimal approach rather than settling for sub-par methods.

Again to reference Israetel’s dissertation, “For a kinetic analysis of the importance of strength in determining athletic performance, two classes of athletic movement must be considered; the movement of the athlete with reference to an external, stationary object (e.g. the ground), and the movement of a movable object, be it an opponent (wrestling, judo), or an implement (tennis, golf, all throwing sports)” (Israetel, 2013). A very common approach to assessing lower body strength in strength and explosive sport athletes is a 1RM back squat assessment (Baechle & Earle, 2008). The back squat, completed with technical proficiency, offers a good reflection of total body-strength, biased toward the lower extremity musculature, and has been correlated with various sport performance characteristics like vertical jumping and sprinting (Comfort, Stewart, Bloom, & Clarkson, 2014; McBride et al., 2009; Wisloff et al., 2004). However, as noted above, a 1RM test in the squat may not be necessarily reflective of in-competition displays of strength and adding other tests *additional to* the 1RM squat test during different phases of the annual training plan are a worthwhile consideration for the SPEG offering more pertinent strength data for monitoring purposes (Kellmann, 2010; Taylor, 2012). Other plausible methods to consider, specifically weighted static squat jumps, will be thoroughly discussed in a later section (See Vertical Jump Testing to Monitor Strength Adaptation). To reiterate a key point from this section, strength specific to strength and explosive sports in the collegiate setting *must not* simply be considered an absolute amount of weight lifted in a commonly programmed exercise or viewed myopically as “Maximum Strength” but rather must also consider the expression of an ability important in various sport-specific conditions (Israetel,

2013; Sokolov, 1974) This specification differs from the conceptual idea of “maximum strength” in that much of what takes place in strength and explosive sport competition can be considered “sub-maximal” in nature and these displays of strength require certain “technical” abilities to produce specific forces containing necessary magnitudes and directions (Stone et al., 2007). Sokolov (Sokolov, 1974) characterized an athlete’s display of strength as “technique” and other authors certainly acknowledge certain “strength” requirements to fulfill “technical” tasks in sport like the “iron cross” in gymnastics or “blocking” in American football (Bompa & Haff, 2009; Hornsby, 2013; Israetel, 2013; Sokolov, 1974). One quickly sees the interrelatedness of strength and technique when observing various sport-specific tasks in strength and explosive sports and the above points warrant further consideration of physiological mechanisms of strength adaptation in the following section to better organize the training/monitoring process.

Physiologic Mechanisms of Strength Adaptation

An exhaustive discussion of intricate physiologic mechanisms of strength adaptation is outside of the scope of this section. However, the more prominent, well-established physiologic mechanisms will be briefly discussed aiming to better understand and transition into the relation to strength and explosive sport and the monitoring of these athletes. This section will deal primarily with physiological mechanisms of strength adaptation and less with anatomical, anthropometric, and biomechanical aspects of strength development as the intention is to highlight underlying *dynamic* aspects of neuro/muscle-physiology and how these areas of physiology relate to monitoring strength adaptation in strength and explosive athletes.

Mechanisms of strength development can be categorized under three headings: 1) neural 2) hypertrophic and 3) anthropometric (Stone et al., 2007, p. 212). The primary factor of maximum force production capability (i.e. maximum strength) has been reported to be muscle cross-

sectional area and more specifically the cross sectional area of Type II muscle fiber (Häkkinen et al., 1998; Maughan, Watson, & Weir, 1983, 1984; Schmidtbleicher, 1992; Schoenfeld, 2010). Noting both direct and indirect data on muscle strength and its relationship to muscle cross sectional area, Maughn et al. (1983) demonstrated from existing literature decades ago that skeletal muscle with greater anatomical and physiological cross sectional area was shown to produce greater forces than skeletal muscle with a smaller cross sectional area also noting differences in fiber types (Maughan et al., 1983). Schmidtbleicher (1992) also noted that the primary determinant of maximal strength production capability is muscle cross sectional area (Schmidtbleicher, 1992). Due to the relationship between Type II muscle fiber cross sectional area and strength development, it is noteworthy to interject that hypertrophy of these type II fibers induced by a properly designed training program seems to directly potentiate future phases of more power-oriented training and is highly rewarded in strength and explosive sport performance tasks (Bissas & Havenetidis, 2008; Nimphius et al., 2010; Young, McLean, & Ardagna, 1995). Several authors have demonstrated similar findings regarding the importance of Type II muscle fiber cross sectional area and force production capabilities. Hakkinen (1989) noted that athletes with a greater percentage of type II muscle fiber possess a greater ability to facilitate hypertrophy as type II muscle fiber display greater resistance training induced hypertrophy (Häkkinen, 1989). Fry (2004) also demonstrated that advanced weightlifters have some of the largest cross sectional areas of type II muscle fibers while also possessing the highest type II/type I cross sectional area ratio of all athletes (Fry, 2004). Conversely, type I muscle fiber is found in higher percentages in athletes who participate in endurance exercise (Bompa & Haff, 2009). Type I muscle fiber has been associated with less force production capability, corresponds to higher maximal oxygen consumption rates and is often referred to as

“slow twitch” in the literature (Bompa & Haff, 2009; Fry, 2004; Stone et al., 2007). Although still worthy of note, the characteristics of type I muscle fiber warrant less focus in this section with the intent of highlighting physiological specifics to strength and explosive sport athletes. McBride and colleagues demonstrated that weightlifters produced significantly higher peak forces, power outputs, velocities, and jump heights in comparison to powerlifters and control groups for jump trials at various loads thus allowing the inference of training induced adaptations and muscle fiber makeup contribution to performance variables (McBride, Triplett-McBride, Davie, & Newton, 1999). Advanced weightlifters have also been recognized by authors to produce some of the highest power outputs ever recorded and have also been noted to have exceptional jumping capabilities, exceptional levels of maximum strength, and exceptional rates of force development measures compared to other strength and explosive sport athletes allowing further practical inference into the importance of Type II muscle fiber content and cross-sectional area to athlete’s strength and explosive sport performance capabilities (Bompa & Haff, 2009; Garhammer, 1993; Stone et al., 2007). In Schoenfeld’s extensive review of the literature, the author notes that hypertrophy involves the expansion of the contractile elements of the muscle while the extracellular matrix increases in size and increases the number of sarcomeres in parallel that can directly enhance the functional capabilities (i.e. force production capability) of the muscle (Schoenfeld, 2010). Demonstrations of muscle cross sectional area’s capability to enhance force production have been made establishing it as a chief determinant in maximum strength development over time. As noted by Schoenfeld, when resistance training-induced hypertrophy takes place, the “architecture” of muscle fiber is also altered (Schoenfeld, 2010). Hypertrophy, as defined above, increases the contractile material of the muscle increasing the capacity of the muscle to produce force. There seems to be a direct relationship between training

interventions and morphological adaptations to muscle fiber. “Explosive” strength training has been demonstrated to significantly increase Type II muscle fiber size directly affecting strength and explosive generating capabilities (Bompa & Haff, 2009; Fry, 2004; Stone et al., 2007). Additionally, some demonstrations have been made noting reductions in Type Ix fiber distribution and concomitant increases in Type IIa fiber distribution (Bompa & Haff, 2009; Folland & Williams, 2007; Williamson, Gallagher, Carroll, Raue, & Trappe, 2001). Some studies, implementing more updated analysis techniques, have demonstrated greater degrees of plasticity of muscle fiber as a result of training interventions and detraining thus warranting thorough consideration from practitioners to adhere to the principle of specificity of training for strength and explosive sport athletes (Gallagher et al., 2005; Stone et al., 2007; Trappe et al., 2006). As noted decades ago by Matveyev, (Matveyev, 1997) developing different physiological characteristics and motor abilities concurrently is very difficult and more recent extensive reviews of the literature have shown that attempting to develop strength and power while attempting to also enhance “endurance” capabilities is essentially counterintuitive and should be avoided for more optimal training adaptations (Bompa & Haff, 2009; Wilson et al., 2012).

Following cross sectional area and muscle architecture, neural variables seem to play a very important role in the development of strength. Although an extensive analysis of neural variables reveals more complex mechanisms of strength development, virtually all neural variables can be categorized, with some overlap, under the following three headings: 1) motor unit recruitment, 2) motor unit rate coding and 3) motor unit synchronization (Bompa & Haff, 2009; Stone et al., 2007). Motor unit recruitment refers to the number of motor units activated during a movement/action against an external load, during “isometric” muscle action (i.e. not producing movement), or to produce a movement of one’s own body/body segments (Bompa &

Haff, 2009; Deschenes, 1989; Milner-Brown, Stein, & Yemm, 1973). Haff and colleagues (Haff, Whitley, & Potteiger, 2001) note that when more motor units are activated, the amount of force generation of the muscle then increases. Henneman (Henneman, Somjen, & Carpenter, 1965) suggests that the size of the given motor unit determines its activation, otherwise known as “the size principle” (Henneman et al., 1965). Henneman’s work simplified suggests that larger motor units have higher activation “thresholds” and are preferentially activated after smaller motor units. High external loads are also accepted to activate larger motor units in a preferential manner (Haff et al., 2001). More recent investigations and contentions from authors suggest that contraction speed, contraction type and overall metabolic state of the muscle also affect the recruitment of motor units rather than always acting in a step-wise fashion from smallest to largest (Duchateau & Hainaut, 1984; Häkkinen, 1994; Jensen, Pilegaard, & Sjøgaard, 2000). This is important in relation to strength and explosive sport athletes regarding training interventions as high-threshold motor units can be stimulated with maximal intent of contraction speed, eliminating the necessity to use very heavy loads in training *every* session in order to reduce fatigue levels and “un-mask” performance characteristics during different phases of training and competition (Hornsby, 2013). Motor unit rate coding relates to the frequency of the motor unit firing or more specifically the frequency at which motor units are activated (Bompa & Haff, 2009; Deschenes, 1989; Stone et al., 2007). With intent to relate rate coding to strength and explosive sport performance capabilities, an important aspect of rate coding to force generation is that force generated by muscle increases without the recruitment of additional motor units (Haff et al., 2001). Van Cutsem’s work in this area indicates that rate coding has a direct effect on determining the speed of voluntary contractions and shows that high motor unit firing rates are associated with greater rates of force development, indicating the specificity to

the strength and explosive sport athlete (Van Cutsem, Duchateau, & Hainaut, 1998). Other authors have noted similar relationships between motor unit firing frequency and rates of force development (Andersen & Aagaard, 2006; Komi & Vitasalo, 1976; Viitasalo & Komi, 1981).

Lastly, motor unit synchronization relates to the simultaneous activation of multiple motor units directly affecting the instantaneous force production capabilities (Bompa & Haff, 2009; Stone et al., 2007). Some discrepancy exists in the literature as to the pronounced effects of motor unit synchronization on strength development with some authors noting a lesser effect on force output than others (Gabriel, Kamen, & Frost, 2006; Milner-Brown et al., 1973; Semmler, 2002; Yao, Fuglevand, & Enoka, 2000). Yao and colleagues, (Yao et al., 2000) demonstrated that the extent of motor unit synchronization's effects on maximum strength, measuring isometrically, appeared to be minimal while others seem to agree that synchronization has a pronounced effect on increased force output (Bompa & Haff, 2009; Milner-Brown et al., 1973; Yao et al., 2000). Semmler and Nordstrom reported (Semmler & Nordstrom, 1998) a higher incidence of motor unit synchronization was found in strength-trained athletes. More work is needed in this area to fully elucidate a cause and effect relationship but, per more recent research from Semmler (Semmler, 2002), motor unit synchronization seems to have more impact on the rate of force development. Stone and colleagues (Stone et al., 2007, p. 214) also note that synchronization does seem to play a more important role in the rate at which force is developed rather than the gross force output and acknowledge that synchronization is seemingly more important for "ballistic" movements (Stone et al., 2007). These points demonstrate the advantage of maximizing this physiologic mechanism for the strength and explosive athlete as many activities in strength and explosive sports depend upon which competitor can produce the required force quicker than their opponent (i.e. sprinting to a loose ball, making a tackle in

American Football, etc.). In conclusion, authors have demonstrated marked increases in strength without concomitant changes in muscle size and architecture (Aagaard, 2003; Cormie, McGuigan, & Newton, 2010c; Gabriel et al., 2006). Other authors have offered evidence that a “lag” in muscle hypertrophy exists from 6-10 weeks of strength training but marked increases in strength have occurred in its absence, lending more credence to the contribution of neural variables to changes in strength (Bompa & Haff, 2009; Buresh, Berg, & French, 2009; Narici, Roi, Landoni, Minetti, & Cerretelli, 1989; Stone et al., 2007). Clearly, neural variables have a pronounced effect on strength development over time and these physiologic mechanisms of strength development warrant thorough consideration from practitioners in the field of collegiate strength and conditioning playing key roles in strength and explosive sport performance tasks requiring both high force output and high rates of force development. Perhaps most importantly regarding the proper defining of strength and physiological mechanisms thereof in relation to collegiate strength and explosive sport is strength’s effect on measures of power. Power, as the product of force production and velocity or otherwise defined as the product of strength and speed, is inherently an important aspect of strength and explosive sport performance. Due to the force component of the power equation (i.e. $\text{Power} = \text{Force} \times \text{Velocity}$), strength immediately presents itself as half of the equation in producing high measures of power. In the following section, strength will be discussed as a key adaptation for strength and explosive sport with special attention to its pronounced effects on the mechanical measures of power and RFD.

Strength as a Key Adaptation in Strength and Explosive Sport

In a review article titled: “How much strength is necessary?” (Stone, Moir, Glaister, & Sanders, 2002), authors demonstrated from available scientific evidence at the time that maximum strength is highly correlated with other mechanical measures, like power and rate of force

development (Stone, Moir, et al., 2002). Strength, as a generalized ability to produce force as discussed in previous sections, is directly involved in *any* action in sport involving the production of force. That is, when considering other pertinent mechanical measures, particularly power and RFD, strength essentially functions as a reservoir or vehicle of sorts from which these other performance variables are drawn (Stone, Moir, et al., 2002). Many authors have demonstrated that increases in strength lead to the ultimate enhancement of other desired training/performance adaptations specific to strength and explosive sport and with intent to stay true to the relation to collegiate strength power/sport, some will be discussed as specific exemplary cases below. In Israel's (Israel, 2013) recent investigative dissertation work with eighty Division I athletes included the assessment of various performance characteristics specific to the current section. The assessments pertinent to the current literature review included the following: 1) sprinting (i.e. RFD) measured by a 20 meter static-start sprint test using timing gates placed at 10m and 20m, 2) vertical jump testing including both static and counter movement jumping with loads of 0, 11kg and 20kg on dual force plates providing jump height data and power production data and 3) an assessment of maximum strength/isometric peak force (i.e. IPF) via isometric-mid thigh pull testing on dual force plates which also provided rate of force development (i.e. RFD) data. This investigation showed that the stronger athletes (as measured by allometrically-scaled peak force) produced larger rates of force development than weaker athletes, produced higher peak powers in loaded jumping than weaker athletes, jumped higher in the unloaded countermovement condition than weaker athletes, and sprinted faster at 10m than weaker athletes (Israel, 2013). Leg strength and power have been reported to be significantly related to sprint speed in athletes analyzed while also noting that the strongest and most powerful athletes were able to run the fastest (Baker & Nance, 1999; Bret, Rahmani,

Dufour, Messonnier, & Lacour, 2002; Cronin & Hansen, 2005). Peterson and colleagues (Peterson et al., 2006) more recently demonstrated that athletes that were stronger and more powerful, compared to weaker athletes, performed better in performance tests seeking to evaluate agility (i.e. change of direction). Barker and colleagues (Barker et al., 1993) and Fry and colleagues (Fry & Kraemer, 1991) both demonstrated key relationships between American Football performance and maximum strength; Fry and Kraemer reporting that ,generally speaking, stronger, more powerful athletes are found as competition level is increased to the Division 1 level from lower tiers of play (Division II, III, etc.). Positive relationships between soccer performance, volleyball performance, ice hockey performance and rugby league performance from athletes with higher strength and explosive levels than comparatively weaker athletes have also been reported by a number of authors, as noted by Bompa & Haff's review of the literature. (Bompa & Haff, 2009, p. 261) (Christou et al., 2006; Ferris, 1995; Gabbett & Georgieff, 2007; Gissis et al., 2006; Hoff, 2005; Melrose, Spaniol, Bohling, & Bonnette, 2007; Silvestre et al., 2006). This lead Bompa and Haff, (Bompa & Haff, 2009, p. 261) to conclude that, "the appropriate application of resistance training can alter the neuromuscular system in a way that improves the athlete's capacity to produce force and improves sport performance."; in agreement with the contention of the author of this literature review that increasing strength (i.e. force production capability) enhances strength and explosive sport performance capabilities. Obviously important to successful performance in strength and explosive sports is the rate at which said forces are developed (RFD), as noted in earlier sections. RFD (See Operational Definitions) is the consideration of the change in force considering a certain time interval or expressed as an equation as the change in force divided by the change in time. As noted by Andersen and Aagard (2006), maximal voluntary strength is strongly related to RFD (Andersen

& Aagaard, 2006). Logically, the ability to produce high amounts of force are of paramount importance when considering having to produce high amounts of force quickly. Further considered, Cormie and colleagues have reported in multiple investigations (Cormie et al., 2010c; Cormie, McGuigan, & Newton, 2011) that producing high amounts of force at high velocities is inherently advantageous to producing high power outputs, intuitively making this concept of maximal strength development over time specific to strength and explosive athletes. It is, however, important to note, as pointed out by Stone and colleagues (Stone et al., 2007, p. 227) that “maximum power and speed are not achieved by heavy strength training alone” but that the “development of power and explosiveness can be augmented through development of strength.” At any rate, the greater the force producing capability of the strength and explosive athlete, the greater capacity to produce high power outputs and velocities of movement; in that these performance characteristics are interrelated. When considering RFD and power as work-rates in strength and explosive sports, the athlete that is able to get the work done the fastest has an advantage over their opponent. The concept of high power outputs and velocities of movement being very important to strength and explosive sport performance is well-established and especially impact the sport performance capabilities of strength and explosive sport athletes (Bompa & Haff, 2009; Harris, Cronin, Hopkins, & Hansen, 2008; Kale et al., 2009; Nimphius et al., 2010; Stone, Sands, Carlock, et al., 2004). The above points, paying special attention to strength’s interrelatedness to other performance characteristics and well-established contribution to ultimately enhancing performance capabilities, establish it as an important facet of training/competition adaptations to closely monitor. The following section will discuss ways of monitoring strength adaptation found in the scientific literature and utilized in the practical

setting with special attention to specificity to the college setting for strength and explosive athletes.

Methods of Monitoring Strength Adaptation

Strength can be measured isometrically or dynamically (Stone et al., 2007, p. 57). Further explained by Stone et al, isometrically-measured strength can have limited usefulness in predicting or monitoring performance in more dynamic activities but isometric measures of strength can still provide important data when force magnitude, rate of force development, time to peak tension and other important force characteristics can be assessed with adequate laboratory testing equipment (Stone et al., 2007, p. 57). With the intent to stay focused specifically on lower extremity strength assessment/monitoring in collegiate strength and explosive athletes, certain investigations including isometrically and dynamically examined strength levels in different body segments will be excluded from this section in order to discuss studies consisting of more pertinent data within the scope of this section's focus and ultimate investigative work by the author. Isometrically-measured strength tests/protocols, as a means of monitoring collegiate strength and explosive sport athlete strength adaptation, must ensure to exhibit mechanical specificity to the given sport in order to provide a valid, reliable measure of strength reasonably transferred to the athlete's given sport. Stone et al, describe the following characteristics to consider regarding specificity of both exercise selection and testing protocols for ensuring better probability of "transfer-of-training" and provision of valid, reliable test measures for monitoring adaptation: 1) movement pattern specificity 2) force magnitude (average and peak force similarity to sport performance tasks 3) Rate of force development (average and peak) 4) acceleration and velocity parameters and 5) ballistic versus nonballistic movements (Stone et al., 2007, p. 171). Stone and colleagues further conclude that the more

“mechanically dissimilar the test becomes, the lower the potential for observing training adaptations.” (Stone et al., 2007, p. 171). Kawamori and colleagues also conclude that a high degree of task specificity is necessary for an isometric test to reliably transfer to a dynamic movement (Kawamori et al., 2006). Specific to monitoring lower extremity strength adaptation isometrically, Smidt (1973) concluded that the extensors of the knee produce peak isometric torque at a 120° knee angle (Smidt, 1973). This is an important point when considering an isometric-monitoring model’s transference capability to the SPEG staff. Data gathered from isometric testing must include joint angle specificity to mechanically similar sport performance tasks in which force output measured is at its highest for assumption of clear transference to sport performance. As noted by Bazzyler’s recent investigation, it is also important to consider the “segment” of the lift in which the force output is lowest, or the “sticking point/region” when mechanical advantage is considered the lowest when one is designing, integrating and interpreting isometric strength testing data (Bazzyler, 2013). Blazeovich et al concluded from their investigation that isometric squats at 90° of knee flexion were highly correlated with subject’s squat 1RM (Blazeovich, Gill, & Newton, 2002). Bazzyler further concludes that isometric squat testing at 90° and 120° theoretically provide strong insight to an athlete’s dynamic squat 1RM (Bazzyler, 2013). The data collection process for valid and reliable isometric squat testing necessitates proper laboratory equipment. Stone et al, also offer various other solutions regarding monitoring strength and characteristics thereof recommending the inclusion of testing athletes on dual force plates by placing athletes in biomechanically specific positions to various sport performance tasks, rendering force-time curves and other important sport performance related data (Stone et al., 2007). Isometric testing on dual force plates entails positioning athletes in mechanically-specific positions to their given sport and having them produce force using a

stationary bar to analyze force production capabilities and characteristics in different mechanically-specific positions to the athlete's given sport. For example, Stone and colleagues suggest that the greatest vertical forces in sprinting are produced at a knee angle of approximately 135°-140° with the trunk upright and that by having athletes, in which sprinting entails an important component to their given sport, set up in the given mechanically-specific position and having them pull on a stationary bar placed approximately at the mid-thigh position could provide important strength/RFD data to the SPEG staff regarding adaptations to training interventions specific to the given mechanical position of the test (Stone et al., 2007, pp. 173-174). Haff et al. (1997) also support this contention and conclude that if isometric testing is used, mechanical specificity of the test is important (Haff et al., 1997). Dual force plates, potentiometers and advanced computer software with the capability of conducting the above mentioned assessments is impractical in many collegiate settings without necessary funding and resources, which will be further discussed in the next section (See Plausibility of Methods in the Collegiate Setting). For these reasons and others; currently, the gold standard for assessing lower body strength is the 1RM squat, particularly in the practical setting, and the 1RM squat is also the most commonly implemented assessment of lower body strength in training studies (Baechle & Earle, 2008; Bazyler, 2013). The 1RM squat has been used to assess lower body maximum strength levels in many studies including untrained subjects, recreationally-trained subjects, and highly trained subjects and has revealed changes in lower extremity strength throughout training intervention studies (Baechle & Earle, 2008; Bazyler, 2013; Bompa & Haff, 2009; Campos et al., 2002; Harris, Stone, O'Bryant, Proulx, & Johson, 2000; Kraemer et al., 2003; Stone et al., 2000). Although 1RM testing is considered a valid, reliable measure of lower body strength, there are certain caveats in implementation of 1RM testing. Different protocols of assessing 1RM in the

back squat have been used causing quite a bit of variability in procedural implementation. As noted by Blazeovich and colleagues, (Blazeovich et al., 2002) some squat studies had participants perform squats to 90° while other studies required subjects to squat to a depth in which the subject's top of the thigh was parallel to the ground, requiring more work on behalf of the subject squatting deeper altering the validity/reliability of the 1RM measure compared to subjects squatting to significantly higher depths in other studies (i.e. 90° knee flexion). As noted by Bazylar, many studies reported 1RM squat strength was assessed without describing the protocol used to test 1RM while others have described the protocol implemented in detail (Bazylar, 2013). Interestingly, there are currently no unanimously agreed upon testing protocols for collegiate strength and explosive athletes describing standardized rest times between 1RM attempts and appropriate adjustments in weight between successful and missed 1RM attempts for a valid, reliable assessment of squat 1RM (Willardson & Burkett, 2006). Also, 1RM testing in the back squat is a fatiguing process, has a high metabolic cost, and requires a certain level of skill in the dynamic movement pattern of the back squat in tested athletes (Bazylar, 2013). Although 1RM squat data is important to the SPEG staff by implementing 1RM tests throughout the annual plan of the athletes, or estimating 1RM via 2RM, 3RM or other estimation methods; other *additional* considerations to monitor strength adaptations are warranted. A contention made by Stone & colleagues is that different muscle actions required in various strength and explosive sports may warrant different testing protocols considering concentric and eccentric components separate from one another by manipulating the nature of the given strength test (Stone et al., 2007, pp. 172-173). Many collegiate strength and explosive sports involve tasks involving no counter-movement. For example, the sprinter's start out of the blocks, American Football linemen producing force from their starting stances, and set volleyball players and basketball

players having to begin their vertical jumps from a static start without a countermovement regularly occur in competition. These specific sport-performance tasks involve the athlete having to generate concentric strength from a static starting position (Kraska et al., 2009).

A 1RM squat test is an example of a strength test involving a dynamic muscle action including eccentric, isometric and concentric muscle actions during different phases of the lift. Researchers have characterized this as a plyometric muscle action and acknowledge the commonality and importance of examining this expression of strength in the practical setting specific to strength and explosive sport (Bobbert, Gerritsen, Litjens, & Van Soest, 1996; Newton et al., 1997; Stone et al., 2007). As noted previously in this literature review, other adaptations to training/competition are worth monitoring specific to strength and explosive sport performance (i.e. power, RFD), but the chief focus of this literature review and ultimate investigation is on strength as a training adaptation important to monitor due to its interrelatedness to the aforementioned performance characteristics and its established specificity to strength and explosive sport (See Strength as a Key Adaptation for Strength and explosive Sport).

Considering the above points/sections, vertical jumping ability has also received much attention in the scientific literature pertaining to sport performance/training adaptation monitoring. Vertical jumping is quite literally a key component of sport performance in many sports determining success over an opponent simply by jumping higher to fulfill a given task (i.e. high jumping, rebounding in basketball, blocking in volleyball, blocking a football from a wide receiver attempting to catch the ball in American football, etc.) Separate from its innate specificity to performance, vertical jumping has also been used for monitoring purposes in sports requiring vertical jumping to a lesser extent to reveal force production characteristics like power and RFD in both weighted and unweighted conditions in order to examine adaptations to training

interventions and competition stress (i.e. weightlifting, soccer). Vertical jump testing is also widely considered to be an easily implemented, safe and effective monitoring method worthy of integration in the practical setting (Bompa & Haff, 2009; Mizuguchi, 2012; Moir, Button, Glaister, & Stone, 2004; Moir, Garcia, & Dwyer, 2009; Moir, Shastri, & Connaboy, 2008; Sams, 2014; Stone et al., 2007) A large volume of research has paid special attention to countermovement vertical jumping ability in both weighted and unweighted conditions but far less attention has been paid to static jumps in comparison; particularly in weighted conditions (Sams, 2014; Taylor, 2012). Further considering the nature of this research, little effort has been made to consider weighted static jumps as a monitoring tool for changes in strength, as virtually all of the studies dealt with jump height, flight time, power production and derivatives thereof, and measures of RFD. Per the previous discussion points in this section and literature review pertaining to ultimate integration in the collegiate setting, the following section will briefly discuss the plausibility of these monitoring methods in the collegiate setting considering reasonable inclusions that emerge as more practical than others. Due to the intent of this literature review and thesis investigation, the following sections will focus on the plausibility of discussed strength monitoring methodology in the collegiate setting and analyze weighted static jumps as a strength test to monitor force production capabilities concentrically from a static (i.e. isometric) start. Following sections will also further consider the capability of specific tests and protocols used in other investigations for monitoring strength adaptation in collegiate strength and explosive sport athletes, noting pros and cons, and ultimately lead to a proposed protocol investigated by the author with potential for implementation in the collegiate setting for monitoring changes in strength.

Plausibility of Methods in the Collegiate Setting

As mentioned in the previous section, certain methods of monitoring strength adaption and derivatives thereof require advanced laboratory equipment. Much of the more technical analyses of strength and explosive sport performance characteristics and adaptations to various training interventions require force platforms or other advanced laboratory equipment including but not limited to: potentiometers placed on the ends of a barbell, 3D motion analysis systems like Vicon® motion analysis equipment, and advanced computer software and signal transducers in order to convert data collected into necessary units to be understood by SPEG staff; inducing consolidated costs greater than \$15,000 (Stone et al., 2007; Thewlis, Bishop, Daniell, & Paul, 2013). The integration of the above equipment into a monitoring model also necessitates individuals who have thorough understanding of how to use said equipment, fix various technical issues, and interpret collected data/troubleshoot intra-session collection problems. In the practical setting, individuals qualified to operate such equipment limit its applicability for use and narrow the opportunity of inclusion in an athlete monitoring model in many cases in the current state of collegiate strength and conditioning/sport science in the United States (Stone, Sands, & Stone, 2004; Stone et al., 2007). That is certainly not to say that it isn't necessary or shouldn't be used but rather that the current state in the practical setting doesn't always permit its inclusion. Also, the cost of this equipment is currently impractical in most collegiate settings due simply to budget constraints by collegiate strength and conditioning departments and allocation of funds elsewhere warranting further consideration of more practical methods of monitoring. In the previous section, methods of monitoring strength adaptation were discussed. Specific to the focus of this literature review and investigation by the author, lower extremity strength monitoring via 1RM squat testing presents itself as the current most commonly implemented and

accepted “gold standard” of strength assessment in the practical setting (See Methods of Monitoring Strength Adaptation). In addition to 1RM squat testing, variations of vertical jump testing were also introduced as safe, easily implemented, effective monitoring tools worthy of consideration in a collegiate strength and explosive sport monitoring effort. The equipment necessary to implement these more practical methods of testing typically already exist in collegiate weight rooms in the United States. Excluding vertical jump protocols requiring modern dual force plates and other necessary software, more cost-effective equipment capable of collecting measures of jump height will be discussed in the following sections. In that the aforementioned monitoring methods present themselves as more practical in the current state of collegiate strength and conditioning in the United States, the following section will pay special attention to weighted static jump investigations due to the focus of this Thesis.

Weighted Static Vertical Jump Testing to Monitor Strength Adaptation

Currently, vertical jump testing is one of the most common forms of strength and explosive athlete testing and monitoring (Bompa & Haff, 2009; Mizuguchi, 2012; Sams, 2014; Stone et al., 2007; Taylor et al., 2012). Vertical jump testing is widely accepted to be a simply implemented and safe testing method providing insightful data to the strength and conditioning staff/sport scientist and is understood to be a less-fatiguing method of performance testing/monitoring than other more invasive methods (Bompa & Haff, 2009; Moir et al., 2004; Moir et al., 2009; G. L. Moir, 2008; Stone et al., 2007). Vertical jumping emerges as a chief component to many strength and explosive sport’s successful performance as its innate large contribution to important aspects of competition is easily observed. More popular American collegiate strength and explosive sports like Football, Basketball and Volleyball directly reward competitors having greater jumping capabilities simply by being able to jump higher than their

opponent (Bayios, Bergeles, Apostolidis, Noutsos, & Koskolou, 2006; Gabbett & Georgieff, 2007; Israetel, 2013; Lidor & Ziv, 2010; Smith, Roberts, & Watson, 1992). Certain strength and explosive competitions are chiefly based upon one's jumping ability, like the high jump and triple jump in track & field. Further considered, virtually all strength and explosive sports consist of jumping at certain points throughout competition or require high amounts of vertical force production for successful performance of various tasks which are seemingly more "horizontal" in nature (Guido Jr, Werner, & Meister, 2009; Kellis, Katis, & Gissis, 2004; Weyand, Sandell, Prime, & Bundle, 2010; Yu, Broker, & Silvester, 2002). Furthermore, a number of authors have demonstrated good correlations between one's vertical jumping ability and ultimate performance capability in sport (Bissas & Havenetidis, 2008; Harris et al., 2008; Till et al., 2011; Young et al., 1995). Perhaps of more interest to coaches and practitioners are vertical jump ability's and force-time characteristics correlates to other important performance tasks. Some important predictive implications of one's ability to jump high include: insight to muscle fiber type, neural mechanisms contributing to explosiveness (i.e. RFD), connective tissue requirements to translate to sprint ability, and the ability to change direction in a more explosive manner (Israetel, 2013; Nimphius et al., 2010; Ostojic, Mazic, & Dikic, 2006). Certain authors have demonstrated strong correlations between vertical jump ability and sprint speed, reporting greater sprint speeds in more explosive and higher jumpers (Cronin & Hansen, 2005; Israetel, 2013; Kale et al., 2009; Nimphius et al., 2010; Peterson et al., 2006). Considering these findings further, as noted previously, sprinting seems more horizontal in nature producing significant horizontal displacement. However, Weyand et al. demonstrated that vertical force production is just as important, if not more important, than forces produced more "horizontally" in high-level sprinters intending to increase sprinting speed (Weyand et al., 2010; Weyand, Sternlight,

Bellizzi, & Wright, 2000). Considering that these aforementioned investigations have shown good correlations between vertical jumping and sprint speed, and vertical force production's contribution to other seemingly horizontally-based sport movements, vertical jump testing emerges as a method of analyzing adaptations to training, practice and competition to better steer the training process.

Another possible implication from one's ability to jump high, is a seemingly positive effect on agility. Agility denotes an athlete's ability to change direction quickly, and when considering the action of planting, applying forces produced by lower extremity musculature into the ground in order to propel the athlete's system mass in a different direction, the specificity of an athlete's vertical jump ability is demonstrated as the two actions are somewhat similar. Further considered, the immediate result of this planting action is the propulsion of the athlete's system mass corresponding with a direction, working against gravity, to produce vertical/horizontal displacement of said mass to a different location. Thus, the resultant change of direction action (i.e. agility), in this context, can be considered to be a type of vertical jump as it inherently has a vertical force component. Other authors have shown relatively strong correlations between vertical jump ability, agility and other explosive lower body movements (Barnes et al., 2007; Carlock et al., 2004; Nuzzo et al., 2008; Peterson et al., 2006). However, that is not to state that a cause and effect relationship exists between increasing one's vertical jump height and concomitant positive changes in sprint technique/speed and agility characteristics. Vertical jump ability's contribution to sprinting and agility has been questioned in other author's investigations showing the extent of vertical jump ability's relation to sprinting and agility as somewhat lower than other studies' findings, and thus warrants further investigation and consideration that sprinting and agility are complex skills in strength and

explosive sport competition that typically result from response to a given stimuli (Alemdaroğlu, 2012; Salaj & Markovic, 2011; Sassi et al., 2009; Sheppard & Young, 2006; Vescovi & McGuigan, 2008). At any rate, when considering the force-time characteristics of a maximal effort vertical jump with intent to produce force as explosively as possible in a loaded or unloaded condition, the specificity to the previously mentioned performance abilities' (i.e. sprinting, agility) force-time characteristics seem to warrant the analysis of vertical jump testing data by practitioners in the field at least during certain times of the annual training plan (Bompa & Haff, 2009; Carlock et al., 2004; Haff et al., 1997; Mizuguchi, 2012; Stone et al., 2007).

As discussed in previous sections, mechanical measures of power and rate of force development are important considerations for the strength and explosive sport athlete. Several authors have investigated the expression of these mechanical measures via vertical jump testing in both weighted and unweighted conditions intending to clarify specific relationships (Bevan et al., 2010; Carlock et al., 2004; Cormie, McBride, & McCaulley, 2008, 2009; Cormie, McCaulley, & McBride, 2007; Cormie, McGuigan, & Newton, 2010a, 2010b; Driss, Vandewalle, Quievre, Miller, & Monod, 2001; Earp et al., 2011; Garhammer, 1993; Haff et al., 1997; Hakkinen, Alen, Kauhanen, & Komi, 1986; Harris et al., 2008; Hasson, Dugan, Doyle, Humphries, & Newton, 2004; Hori et al., 2008; Israetel, 2013; Kavanaugh, 2014; Kraska et al., 2009; McBride et al., 1999; Ronglan, Raastad, & Børgesen, 2006; Sams, 2014; Sleivert & Taingahue, 2004; Stone et al., 2003). Readers are encouraged to consult the referenced works for further understanding of vertical jump testing specific to the mechanical measures of power and RFD, as the remainder of this section will focus specifically on the implementation of static vertical jumps to potentially monitor changes in absolute and relative strength rather than its derivatives (i.e. power, RFD, etc.), as considerably less attention has been paid to weighted static

jumps' potential to monitor changes in relative and absolute squat strength, specifically. In that a relationship between relative and absolute squat strength and vertical jump ability emerges from the literature, the remainder of this literature review will briefly investigate the types of vertical jumps used to elucidate these relationships, offer insight as to why these types of jumps were used, and offer a comprehensive discussion of static jumps as they are the focus of the authors' investigation. Literature reviewed will consider pros and cons of said methodology relating to normative strength and ability levels in collegiate strength and explosive athletes, while considering budget and time constraints in this setting, and will ultimately lead to the offering of potentially more reasonable methodology with these findings in mind. It is noteworthy that only studies pertaining to the above listed criteria will be included in the remainder of this literature review and that all studies including some aspect of vertical jump testing included with other performance tests, potentiation complex studies including vertical jump assessments and other investigations simply noting vertical jump abilities related to fatigue and other aspects of performance do not warrant inclusion as they are beyond the scope of this literature review. Furthermore, the author's intent is to only include studies meeting the following criteria in the remainder of this section: studies investigating correlations between squat strength and weighted and unweighted countermovement and static jumps with special attention to studies investigating static jumps, studies offering standardized loading schemes for these tests, studies specific to strength and explosive sport athletes including the previous criteria, and lastly, any studies aiding in the further understanding of underlying aspects of the discussed investigations' methodology or reasoning, deemed necessary by the author.

The two predominant forms of vertical jump testing found in the scientific literature are the "countermovement" (i.e. CMJ) and "static" jumps (i.e. SJ); also referred to as "squat" jumps

but hereafter referred to as “static” (Mizuguchi, 2012; Sams, 2014; Taylor et al., 2012). Per Taylor’s recent comprehensive review of the literature, vertical jumps, countermovement vertical jumps particularly, were reported to be the most common form of athlete monitoring among high level coaches surveyed (Taylor, 2012; Taylor et al., 2012). Interestingly, no consensus existed among coaches as to which vertical jump testing methods and variables of said tests were “most important”, although “countermovement” jumping emerged as the most prominent form of athlete testing/monitoring (Taylor et al., 2012). Countermovement jumping is characterized by a descent phase utilizing the stretch-shortening cycle (i.e. SSC) to increase the proceeding “concentric” jumping action. Thus an “eccentric” stretch precedes the vertical jump in a countermovement jump. As noted by Enoka et al, certain physiologic mechanisms allow an increase in jump height when countermovement jumping compared to a “static” jump attempting to eliminate these actions (Enoka & Duchateau, 2008). These are: the allowance of increased time to develop force, storage of elastic energy, potentiating effect of a pre-stretch, and the stretch reflex (Enoka & Duchateau, 2008). Due to the specificity of this jump to jumps undertaken in strength and explosive sport competition, countermovement jumps certainly warrant inclusion in the testing protocols of collegiate strength and explosive athletes, offering insight into the athlete’s ability to utilize these physiological mechanisms. Coaches and investigators have certainly recognized CMJ ability’s specificity to competition as it is often included in athlete monitoring models and scientific investigations, as previously discussed. More specific to this thesis and investigation, static jumps are characterized as “concentric-only” in nature and are also specific to aspects of strength and explosive sport competition as many important actions are preceded by a “static” start. Considerably less attention has been paid to static jumps in the scientific literature and the remainder of this section seeks to focus on static

jumps and, particularly, the lack of investigations including weighted static jumps. SJ's seek to elucidate an athlete's ability to produce explosive force from an "isometric" starting position, similar to a sprinter's start out of the blocks, an American football lineman's starting position out of a "three-point stance" and a basketball forward's vertical jump to pull down a rebound from a static position. Static jump trials essentially attempt to eliminate the previously mentioned physiologic mechanisms of the stretch-shortening cycle (SSC), which aid in increases in jump height, to better understand an athlete's ability to produce force from a static starting position. Much of the literature is in agreement that static jump trials are undertaken with the athlete descending into a 90° knee angle and holding the position for around 3 seconds, typically ensured by a "3-2-1" countdown preceding the jump to mitigate the contribution of the SSC (Blache & Monteil, 2013; Carlock et al., 2004; Haff et al., 1997; Hornsby, 2013; Israetel, 2013; Kavanaugh, 2014; Kraska et al., 2009; Sams, 2014; Stone et al., 2003). Although SJ variables seem to respond similarly to CMJ variables, certain more recent findings have revealed some fundamental differences in CMJ and SJ variables relating to pertinence of use for athlete monitoring and warrant consideration. Sams (2014) demonstrated that SJ variables were more "sensitive" to fatigue levels throughout a competitive season of soccer, testing Division I soccer players, noting marked statistical differences between allometrically scaled peak power collected from SJ trials and SJ variables being better indicators of fatigue than data collected from CMJ trials (Sams, 2014). Raastad and Hallen, noted that decreases in SJ height were associated with decreased torque generation (i.e. force production) and maximal voluntary contraction (i.e. MVC) magnitude (Raastad & Hallén, 2000). A number of other authors have also demonstrated that SJ variables seem to be more sensitive to fatigue levels than CMJ variables likely due to the mitigation of the SSC in SJ trials compared to the pronounced utilization of the SSC in CMJ

trials thus, “masking” lower extremity musculature force production capabilities to a greater extent in CMJ trials compared to SJ trials (Byrne & Eston, 2002; Gee et al., 2011; Hoffman et al., 2002; Hortobagyi, Lambert, & Kroll, 1991; Raastad & Hallén, 2000; Robineau et al., 2012; Sams, 2014). Some predictive implications from the above references are that force production capabilities of lower extremity musculature seem to be more related to SJ variables collected than CMJ variables, when intending to investigate lower extremity musculature force production, specifically. That is, although CMJ variables are certainly important to performance and athlete monitoring, when the intent of the investigator is to elucidate lower extremity muscular force production capability, SJ variables seem to offer more insight than CMJ variables in comparison, supporting the concept that weighted static jumps may allow monitoring of lower extremity muscular strength (i.e. force production). Although these studies warrant mentioning, it must be noted again that the focus of this section is on SJ’s potential ability to monitor strength adaptation in unweighted/weighted conditions rather than thoroughly discussing studies focusing on fatigue monitoring via SJ trials; although fatigue monitoring via SJ’s variables is certainly another important provision in a comprehensive athlete monitoring model that is worthy of consideration by the SPEG staff. A series of studies worthy of mention as part of an ongoing long-term athlete monitoring study at East Tennessee State University have reported moderately strong to strong correlations between isometric peak force (assessed via custom built rack, by subjects standing on force plates and pulling as explosively as possible on a “stationary” bar, with fixed knee angles associated with strength power sport performance (i.e. approximately 130° knee flexion) often referred to as an isometric mid thigh pull in the literature), allometrically scaled peak force, and measures of RFD at important time points (i.e. 50, 90, 250ms) with weighted static jump variables but will not be thoroughly discussed due to the

intention of those author's investigations and focus of this literature review. These studies included Division I strength and explosive athletes jumping with fixed loads of 0, 11, 20 kg in both CMJ and SJ trials seeking to elucidate jump height, power, RFD and other force production derivatives but not changes in squat strength, specifically, thus negating significant impact on the author's personal investigation study design (Hornsby, 2013; Israel, 2013; Kavanaugh, 2014; Mizuguchi, 2012; Sams, 2014). Many other athlete monitoring studies also reporting weighted static jump data are also excluded from this section due to the same reasons. The remainder of this section will discuss studies pertaining to SJ correlates with strength levels, noting certain studies reporting strength measures, and also consider the absence of studies intending to elucidate strength adaptations from weighted static jump trials. Stone et al. investigated power and maximum strength relationships during performance of dynamic and static unweighted and weighted jumps in 22 subjects of varying levels of strength and training ages ranging from 7 weeks to 15 years intending to gain a more accurate perspective on maximum strength's effect on force production and its derivatives (i.e. power, RFD). 1RM squats were assessed for both dynamic squats and "static" squats (i.e. concentric phase only) requiring subjects' top of thigh to be parallel to the ground. (Stone et al., 2003) Subjects were statistically divided into the strongest 5 and weakest 5, with the remaining subjects data also reported. Subjects then completed the jump trials with loads at 0, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%1RM. Subjects' feet left the floor in all conditions except for the 100%1RM load. All trials were completed on force plates to accurately assess force production and its derivatives. Static jump power output yielded higher correlations to 1RM squat than CMJ's at every loading condition. Static jump power output also yielded strong to very strong correlations with 1RM static squat and dynamic squat with loads from 0-90% and moderately strong (0.75) correlations at 100%

1RM. Stone et al. inferred that due to the strong relationship between static jumping power and 1RM static squat strength, hypothetically, static jumping power could be improved by increases in the 1RM static squat. These findings also seem to indicate, predictively, for the inverse to be true; that is, increasing static jumping power could be strongly related to concomitant increases in static/dynamic squat strength. Carlock et al. demonstrated strong correlations between static jump variables and weightlifting performance in 64 high level weightlifters (Carlock et al., 2004). Pertinent to the focus of this thesis, Carlock et al. reported static jump heights of subjects were strongly correlated with subjects' 1RM in the back squat ($r=0.72$) although static jumps were only assessed in the "unweighted" condition by subjects placing their hands on hips, somewhat reducing its impact on this discussion (Carlock et al., 2004). Haff et al. also reported unweighted static jump data which correlated strongly with IPF (i.e. isometric peak force) in eight subjects of varying levels of strength but again neglected reporting squat strength thus reducing the impact of findings to this discussion.(Haff et al., 1997) Haff & colleagues also reported unweighted static jump data in elite female weightlifters revealing a moderately strong correlation ($r=0.57$) between static jump height and IPF measured with the isometric mid thigh pull but neglected reporting squat strength, thus reducing pertinence to this discussion (Haff et al., 2005). Kraska et al. investigated 63 Division 1 strength and explosive athletes strength characteristics in relation to vertical jump ability including a static jump assessment in an unweighted and weighted condition (i.e. 0, 20kg). Moderate to moderately strong correlations were reported for SJ height at 20kg and IPF, IPFa, and RFD measures at 50, 90 and 250ms but the strength measures were reported from isometric mid thigh pull testing and squat strength was again, unreported, also reducing this study's specificity to the desired criteria; yet warrants mention as the measure of strength used in relation to static jump ability yielded favorable

correlations specific to the focus of this section (Kraska et al., 2009). Also worthy of note, Kraska et al. reported less decrement in stronger subjects' jump height from the unweighted to weighted condition. In another study worthy of consideration, McBride and colleagues investigated differences in strength and power characteristics in weightlifters, powerlifters and sprinters via unweighted and weighted CMJ trials on force plates.(McBride et al., 1999) An important note, is that 1RM's and loaded jumps were conducted in a smith machine and not assessed as discussed in previous sections with a barbell and free weights; further affecting the specificity to this discussion. However, McBride et al. reported smith machine squat strengths of each subject in 1RM format and revealed that the weightlifters mean 1RM in the smith machine squat was higher than the other groups. Although the unweighted and weighted jumps performed in the study were CMJ trials thus reducing specificity to the current discussion, weightlifters produced higher power outputs and peak forces during weighted and unweighted jumps at each load compared to the other groups. As other factors may have also contributed to these findings, a cause and effect relationship must not be automatically implied; yet taking the data into consideration, the subjects with greater smith machine squat 1RM's produced higher peak forces and peak powers in both unweighted and weighted conditions. Hence, loaded vertical jumping force production characteristics, although CMJ trials in this study, revealed a relationship between jump ability and squat strength, further supporting other investigations revealing strong correlations between vertical jump variables and squat strength. (Blackburn & Morrissey, 1998; Carlock et al., 2004; McBride et al., 1999; Nuzzo et al., 2008; Stone et al., 2003; Wisloff et al., 2004). As previously mentioned, many other authors have investigated loaded CMJ's with some even including SJ trials in their investigations, but these investigators sought to examine measures of power and derivatives of force production while excluding any measure of squat

strength, greatly reducing the number of studies pertinent to the current discussion. Aside from the studies from the investigations discussed above, to the knowledge of the author at the time of writing this thesis, no other studies have investigated weighted static jumps with the intent to measure, correlate or monitor changes in squat strength, specifically, either acutely or for long term strength and explosive athlete monitoring purposes; specifically focusing on weighted static jumps and their potential to reveal changes in relative or absolute squat strength; making the following investigation the first of its kind (See Chapter 2). In that Stone & colleagues' (Stone et al., 2003) and Carlock and colleagues' (Carlock et al., 2004) findings specific to SJ variables, among other points and investigations discussed in this section, seem to reveal a relationship between lower extremity musculature force production capabilities and SJ variables, the authors sought to clarify the relationship between a standardized weighted static jump protocol considering normative levels of squat strength in collegiate strength and explosive athletes in an attempt to elucidate whether or not the specific weighted static jump protocol had the potential to reveal and monitor changes in squat strength, specifically, with the investigation being exploratory in nature.

CHAPTER 3

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN A STATIC JUMP PROTOCOL AND SQUAT STRENGTH: A POTENTIAL PROTOCOL FOR COLLEGIATE STRENGTH AND EXPLOSIVE ATHLETE MONITORING

Original Investigation

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Abstract

Purpose: The purpose of this study was to examine the potential of a static jump protocol to monitor training adaptation in collegiate strength and explosive athletes. **Methods:** Forty-one young (20.80 ± 2.44 years), healthy volunteers, thirty-one being current or recently former NCAA division-one athletes, reported estimated back squat 1RM's based on the most recent block of training and completed a static jump protocol. Five loads were used to estimate static jump height via flight time from portable contact mats. Males ($n=19$, est. 1RM 141.29 ± 32.02 kg) used: 0kg (PVC pipe), 20.42kg (45lbs), 43.10kg (95lbs), 61.25kg (135lbs), and 83.94kg (185lbs). Females ($n=21$, est. 1RM 71.56 ± 19.64 kg) used: 0kg (PVC pipe), 12.70kg (28lbs), 20.42kg (45lbs), 29.49kg (65lbs), and 43.10kg (95lbs). **Results:** A number of variables were calculated from obtained jump height. Large to very large correlations were found between squat strength and jump height of all trials in females. The percent change in JH 1-5 (0kg to 83.94kg) produced large to very large correlations with male squat strength. Large to very large correlations were also found between the mean jump height for all conditions with relative squat strength in both sexes. These variables showed shared variance of up to 71% with relative squat 1RM. **Conclusions:** It appears that monitoring loaded static jumps may have a greater likelihood of reflecting changes in squat 1RM.

INTRODUCTION

In relation to collegiate strength and explosive sport performance, monitoring the training process affords the strength and conditioning professional important abilities. Some of the more prominent abilities are: 1) the ability to control the development of unnecessary amounts of fatigue during different phases of the training plan and competitive season, 2) the ability to adjust training variables appropriately to promote optimal training adaptations and performance preparations (e.g. peaking), and 3) precise monitoring offers an objective lens through which to view training, recovery and coaching interventions for their effectiveness (Banister & Calvert, 1980; Bompa & Haff, 2009; Issurin, 2009; Medvedyev, 1986; Olbrecht, 2000; Sands & McNeal, 2000; Sands & Stone, 2005; Siff & Verkhoshansky, 2004; Smith, 2003; Stone et al., 2007). Logically, the potential to predict and “post-dict” (Sands & McNeal, 2000) various responses to training and, ultimately, competition performance is important for strength and conditioning professionals and sport coaches necessitating monitoring of the training process. Of particular importance to performance in strength and explosive sports, is the monitoring of lower extremity strength. Many authors have reported that lower extremity strength is associated with explosive movements such as sprinting, jumping and changing direction quickly (Barnes et al., 2007; Carlock et al., 2004; Cronin & Hansen, 2005; Israetel, 2013; Kale et al., 2009; Nimphius et al., 2010; Nuzzo et al., 2008; Peterson et al., 2006; Wisloff et al., 2004). For example, Wisloff et al reported strong correlations between squat strength, vertical jump height and sprint speed in high level soccer players (Wisloff et al., 2004).

Due to its contribution to explosive movements, lower extremity strength has emerged as a particular focus of testing in the practical setting (Baechle & Earle, 2008). Currently, the 1-repetition maximum (1RM) back squat is considered the gold standard for measuring maximum

strength in lower extremity musculature in the practical setting (Baechle & Earle, 2008; Bazyler, 2013). However, 1RM back squat testing induces relatively high amounts of fatigue and consumes time in the practical setting at the expense of an actual training session or sport practice. Thus, 1RM testing should be implemented strategically at certain times of the year, and be supplemented with more regular implementation of other tests, such as vertical jumping, that are less fatiguing and less time consuming. Two predominant forms of vertical jump testing have been reported to be popularized and integrated into the practical setting for athlete monitoring and testing (Mizuguchi, 2012; Sams, 2014; Taylor, 2012; Taylor et al., 2012). Of the two, countermovement jump (CMJ) is the more common form among high level coaches surveyed (Taylor et al., 2012). Interestingly, no consensus existed among coaches as to what vertical jump testing methods and variables of said tests were most meaningful (Taylor et al., 2012). While CMJ is more commonly used in monitoring, some static jump (SJ) variables, based on more recent findings, may be able to provide better insight into lower extremity strength and fatigue monitoring (Blache & Monteil, 2013; Byrne & Eston, 2002; Carlock et al., 2004; Gee et al., 2011; Haff et al., 1997; Hoffman et al., 2002; Kraska et al., 2009; Raastad & Hallén, 2000; Robineau et al., 2012; Sams, 2014; Stone et al., 2003).

Stone and colleagues (Stone et al., 2003) investigated relationships between maximum strength and peak power in CMJ and SJ with loads ranging from 0 to 100% of self-reported squat 1RM. Static jump peak power had larger correlations ($r=0.75-0.94$) to static squat jump 1RM at every loading condition compared to CMJ related dynamic 1RM ($r=0.60-0.88$). Other authors have also reported larger correlations between variables of SJ and measures of strength and explosiveness compared to CMJ (Carlock et al., 2004; Haff et al., 2005; Kraska et al., 2009). Carlock and colleagues reported SJ and CMJ variables relationship to squat 1RM in sixty four

junior and resident national-level weightlifters. One of the variables was a peak power to body mass ratio. This ratio for SJ produced a coefficient of 0.42 compared to this ratio for CMJ yielding a coefficient of -0.17. Furthermore, SJ height produced a larger correlation coefficient with squat 1RM of 0.58 compared to 0.52 for the CMJ trial (Carlock et al., 2004).

Haff and colleagues examined unweighted SJ and CMJ in eight men with at least two years of training experience in explosive exercise (Haff et al., 1997). Static jump peak force produced higher correlations than CMJ peak force with isometric rate of force development and isometric peak force in the isometric mid-thigh pull. Static jump peak force produced a correlation coefficient of 0.57 with isometric rate of force development and 0.76 with isometric peak force compared to 0.44 and 0.53 for CMJ peak force with the same variables. Furthermore, SJ height had correlation coefficients of 0.82 and 0.56 with isometric rate of force development and isometric peak force. On the other hand, CMJ height had coefficients of 0.70 and -0.35 with isometric rate of force development and peak force. Additionally, SJ height produced the highest correlation coefficient out of the other SJ variables collected, including SJ peak force, SJ rate of force development, and SJ peak power, with rate of force development collected from dynamic mid-thigh pull trials (Haff et al., 1997).

The reported correlations between the SJ and measures of strength and explosiveness suggest the possibility that variables of SJ may have large shared variance with, and thus, high probability of inferring changes in strength and explosiveness. In particular, SJ height may be such a variable that possesses large shared variance while being easy to obtain in practical settings. In practical settings, the use of SJ for monitoring purposes could reduce fatigue induced from 1RM squat testing and save time for resistance training sessions, practices or conditioning activities. To our knowledge, no studies have investigated a SJ protocol to potentially use as a

monitoring tool for lower extremity strength in collegiate strength and explosive athletes. Therefore, the purpose of the study was to examine relationships between jump height related variables from a SJ protocol and estimated squat 1RM as the first step towards using SJ as a monitoring tool for lower extremity strength.

METHODS

Experimental Approach to the Problem

In order to examine the relationship between squat strength and variables obtained from a static jump protocol, forty-one subjects reported estimated 1RMs for the back squat exercise and completed a static jump protocol. A number of variables were calculated from jump height and/or system mass. These data were statistically analyzed for correlations with estimated squat 1RM. Larger correlations indicate greater shared variance between squat 1RM and a SJ protocol variable and consequently a higher probability of successfully inferring a change in squat 1RM.

Subjects

The subjects in this study all voluntarily participated. All subjects were young, healthy adults (age: 20.81 ± 2.44 years, height: 173.78 ± 8.99 cm, mass: 79.99 ± 13.40 kg). This investigation was submitted and approved by the Institutional Review Board (IRB) of East Tennessee State University. All subjects were informed of the benefits and risks of the investigation prior to signing an institutionally-approved informed consent document to participate in the investigation. Of the subjects, thirty were competitive Division 1 strength and explosive athletes or had recently completed their competitive career. Eleven were members of the university's Reserve Officers' Training Corps (ROTC) chapter or were undergraduate or

graduate students in the exercise science program. There were nineteen males (age: 21.84 ± 2.93 years, height: 179.73 ± 7.50 cm., mass: 85.20 ± 10.09 kg) consisting of track and field athletes, weightlifters, or members of the university ROTC chapter and four graduate or undergraduate students in the exercise science program. Each subject self-reported at least two years of resistance training experience prior to the study. The twenty-two females (age: 19.91 ± 1.48 years, height: 168.64 ± 6.79 cm, mass: 75.48 ± 14.46 kg) were NCAA Division I softball players. No injuries were reported throughout the data collection.

Squat Strength Estimates. Squat strength was reported as an estimated 1 repetition maximum (1RM) based on subjects' training log of the most recent training block. Four subjects who were graduate or undergraduate student-volunteers did not provide a training log and thus were prompted to be honest in their representation of their estimated squat strength. Allometric-scaling technique (Sq-ALL) and a squat 1RM to body mass ratio (Sq-BM) were compared as a method to provide measures of relative squat strength. Sq-ALL was calculated as squat 1RM divided by each subject's body mass to the two-thirds power. Allometry (allometric-scaling) appears to provide a more effective way to standardize performance controlling for body dimensions compared to ratio scaling (Batterham & George, 1997; B. Jacobson, 2013). Theoretically, muscle force is proportional to muscle cross-sectional area and thus increases with body size in a manner proportional to mass^{0.67} (Jaric, Mirkov, & Markovic, 2005).

Procedures

Data Collection. Subjects were prompted to refrain from and reported no vigorous physical activity within forty-eight hours prior to testing. Subjects were first weighed on an electronic scale to the nearest 0.1kg for body mass measurements. Subjects, in groups of two, then completed a warm-up protocol and a static jump protocol. The warm up protocol consisted

of twenty-five jumping jacks, one jump at 50% of perceived maximum effort, followed by a 75% of perceived maximum effort jump and one, 100% of perceived maximum effort practice-jump. All warm-up jumps were performed with a polyvinylchloride (PVC) pipe placed just below the 7th cervical vertebrae. Subjects were instructed to place the barbell used in the actual testing session in the same location as the PVC pipe in the warm-up throughout the static jump protocol, typically referred to as the “high-bar” position. Subjects were given up to 30 seconds of rest between the warm-up trials. Subjects were instructed during the warm up to descend to a 90° knee angle, which was measured by investigators via a hand-held goniometer and visually checked in each proceeding jump trial thereafter (Carlock et al., 2004; Haff et al., 2005; Haff et al., 1997; Kraska et al., 2009; Sams, 2014; Stone et al., 2003a). All weighted static jumps were completed within a squat rack containing safety bars placed just below the bottom of the barbell for safety purposes. If the investigators or subjects felt spotters were needed during any trials, spotters were also placed at each end of the barbell. Subjects were instructed to assume the “ready position” after un-racking the barbell, at the 90° knee angle. When the appropriate knee angle was achieved, a “3-2-1-jump” command was given and the subjects jumped. Jump heights were recorded via the JustJump® contact mat (Probotics, Huntsville, AL). The JustJump® system has been shown to have sufficient validity and reliability to estimate jump height (Leard et al., 2007). The mat was attached to a hand-held computer that records flight time and estimated jump height.

Protocol. A SJ set-up commonly used in previous studies was also employed in our protocol by descending to a 90° knee angle and pausing for three seconds prior to jumping without arm swing (Carlock et al., 2004; Kraska et al., 2009; Sams, 2014). Stone et al. (2003) reported consistently larger correlations at a wide range of loads with SJ compared to CMJ.

Thus, loading conditions were used (Stone et al., 2003). While Stone et al. used ten loading conditions up to 100% of 1RM, this does not appear practical. On the other hand, some other studies used unweighted SJ. However, there is a concern that unweighted SJ does not reflect squat 1RM as much as weighted conditions because of the lower intensity in the unweighted condition. Due to the lack of consensus on an optimal number of loading conditions to adequately infer an athlete's maximum squat strength, unweighted and an additional four weighted conditions were deemed reasonable and chosen to examine the practicality and adequacy to infer an athlete's squat 1RM using the current protocol or the like.

The actual loads were chosen considering time constraints in the practical setting, normative strength levels in the collegiate setting (J. Hoffman, 2006), along with the authors' practical experience. Males used the following loads: 0kg (condition 1: PVC pipe or "weightless"), 20.42kg (condition 2: 45lbs), 43.10kg (condition 3: 95lbs), 61.25kg (condition 4: 135lbs), and 83.94kg (condition 5: 185lbs) (Table 2.1-2.3). For females, the loads were: 0kg (condition 1: PVC pipe considered "weightless"), 12.70kg (condition 2: 28lbs), 20.42kg (condition 3: 45lbs), 29.49kg (condition 4: 65lbs), and 43.10kg (condition 5: 95lbs) (Table 2.1-2.3). Subjects were given between approximately thirty and sixty seconds of rest between trials and instructed to perform the following trial upon perceived readiness. At least two trials were performed in each condition and the average of the two was used for statistical analysis to reduce random error and reveal a more true score (Henry, 1967; Kroll, 1967). A 3cm. (1.18in.) within-condition difference between trials was used as a threshold, above which another trial was granted. While a smaller difference could have been used (Moir et al., 2008; Stone et al., 2003), the 3-cm difference was deemed practical based on pilot data collection and to minimize time consumed for testing by reducing extra trials.

Table 2.1 System Masses

	Males	Females
Condition 1	85.20±10.09	75.48±14.46
Condition 2	105.62±10.09	88.18±14.46
Condition 3	128.30±10.09	95.90±14.46
Condition 4	146.45±10.09	104.97±14.46
Condition 5	169.14±10.09	118.58±14.46

**Values expressed as means ± standard deviations in KG.*

**System Mass=Load + Body Mass.*

Table 2.2 Changes in System Mass from Condition 1

	Males	Females
Condition 1 to 2	20.42	12.70
Condition 1 to 3	43.10	20.42
Condition 1 to 4	61.25	29.49
Condition 1 to 5	83.94	43.10

**Values expressed in KG.*

Table 2.3 Percent Change in System Mass from Condition 1

	Males	Females
Condition 1 to 2	24.28±2.81	17.41±3.22
Condition 1 to 3	51.25±5.92	27.99±5.18
Condition 1 to 4	72.83±8.42	40.42±7.48
Condition 1 to 5	99.80±11.54	59.07±10.93

**Values expressed as means ± standard deviations.*

Variable Calculations. For practical consideration, variable calculations were completed via Microsoft Excel (Table 2.4). Jump height (JH) was used to calculate JH change and relative JH change from condition 1 to each of the remaining conditions. To obtain some of the variables, system mass was first calculated by adding the subject's body mass and a bar mass for each jump condition (Table 2.1). Ratio was calculated by dividing jump height by system mass for each condition to account for applications of the same loads for individuals of different sizes and strength levels (Table 2.4). Ratio change and relative ratio change from condition 1 were calculated similarly to JH change and relative JH change, except that ratios replaced JH data in the example formula above. Furthermore, the following variables were calculated from jump height and/or system mass: Mean JH (average performance of all conditions), ratio, STDEV JH (standard deviation of all conditions as performance variability), CV JH (coefficient of variation of all conditions as relative performance variability), performance slope (slope of five jump heights against five system masses), and relative performance slope (a slope of percent change in five jump heights against percent changes of system masses) for each subject. CV JH was calculated as a subject's coefficient of variation by dividing STDEV JH by Mean JH multiplied

by 100. Slope was calculated as a slope of the best fit line when a subject's five system masses and jump heights were plotted on the x and y axes, respectively. Relative performance slope then represented a slope when a subject's five percent changes in system mass and in jump height were plotted on the x and y axes, respectively (See Table 2.4 for Variable Calculations).

Table 2.4 Summary of Examined Variables

Variables	Definition of Variable
JH	Jump height from each of the five conditions (e.g. JH1 for condition 1)
SM	System Mass for each of the five conditions (e.g. SM 1 for condition 1)
SM change	Change in system mass from condition 1 (e.g. SM change 1-2 for system mass change from condition 1 to 2)
Rel. SM Ch.	Percent change in system mass from condition 1 (e.g. Rel. SM Ch. 1-2 for percent change in system mass from condition 1 to 2 = $\frac{SM\ change\ 1-2}{SM_1} \times 100$)
Ratio	Ratio of JH to SM (e.g. Ratio 1 for a ratio of JH1 to SM1)

JH Change	Change in JH from condition 1 (e.g. JH change 1-2 for change in JH from condition 1 to 2)
Ratio Change	Change in ratio (e.g. Ratio change 1-2 for change in ratio from condition 1 to 2)
Rel. JH Ch.	Percent change in JH from condition 1 (e.g. Rel. JH Ch. 1-2 for percent change in JH from condition 1 to 2 = $\frac{JH\ change\ 1-2}{JH1} \times 100$)
Rel Ratio Ch.	Percent change in ratio from condition 1 (e.g. Rel Ratio Ch. 1-2 for percent change in ratio from condition 1 to 2 = $\frac{Ratio\ change\ 1-2}{Ratio\ 1} \times 100$)
Mean JH	Average of JH from the five conditions.
STDEV JH	Standard deviation of JH from the five conditions.
CV JH	Coefficient of variation of JH from the five conditions as $\frac{STDEV\ JH}{Mean\ JH} \times 100$)
Perf. Slope	A slope of the best fit line with JH 1-5 on the y-axis and SM 1-5 on the x-axis. Calculated using the SLOPE

	function in Microsoft Excel.
Rel. Perf. Slope	A slope of the best fit line with Rel. JH Ch. 1-5 on the y-axis and Rel. SM Change 1-5 on the x-axis. Calculated using the SLOPE function in Microsoft Excel.

Statistical Analyses

IBM SPSS Statistical Software (IBM, Armonk, NY, Version 17) was used to calculate intraclass correlations coefficients (ICC) for jump height. Coefficients of variation were also calculated for jump height from each condition using the spreadsheet provided by Hopkins (Hopkins, 2011). Cohen's (d) effect sizes were also calculated as a standardized within-condition difference between trials (Cohen, 1977). In this case, a smaller effect size was considered better, for test-retest reliability of jump height. Correlations were calculated using Pearson's *r* in Microsoft Excel. A correlation is the strength of a relationship between two variables. A positive correlation between two variables means that the variables increase together, and a negative correlation means an inverse relationship. Hopkins has rated correlations as *r*= 0.0-0.1 (trivial), 0.1-0.3 (small); 0.3-0.5 (medium); 0.5-0.7 (large); 0.7-0.9 (very large); 0.9-1.0 (nearly perfect); and 1.0 (perfect) (Hopkins, 2002).

RESULTS

Group means ± standard deviation for males were 141.29±32.02kg, 1.66±0.30, and 7.30±1.39kg·kg^{-0.67} for absolute squat 1RM (Sq-ABS), squat 1RM to BM ratio (Sq-BM), and allometrically-scaled squat 1RM (Sq-ALL), respectively. For the females, values were

71.56±19.64kg, 0.98±0.32, and 4.10±1.23 kg·kg^{-0.67}, respectively. The four external loads used in the SJ protocol for males and females corresponded to the following percentages of Sq-ABS, respectively: 15.08 ± 3.05% and 18.90 ± 4.65% for condition 2, 31.83 ± 6.45 % and 30.39 ± 7.48% for condition 3, 45.24 ± 9.16% and 43.89 ± 10.80% for condition 4 and 62.00 ± 12.56% and 64.14 ± 15.78% for condition 5.

Intraclass correlation coefficients ranged from 0.95-0.99 for jump height measures in males and females. Coefficients of variation ranged from 2.0-5.8% in females for all conditions, 2.1-4.4% for conditions 1,2,3 and 5 for males; while condition 4 produced a 10.3% coefficient of variation for males. Effect sizes ranged from 0.05 to 0.09 for males and females. Both males and females showed a declining trend in jump height from JH1 through JH5 (Tables 2.5, 2.6). The declining trend corresponded to the changes from JH1 of -10.52±3.44 cm (JH1-2), -19.21±4.95 cm (JH1-3), -24.67±5.53 cm (JH1-4), and -30.85±6.12 (JH1-5) for males and JH1 of -4.76±1.43cm (JH 1-2), -8.08±1.84cm (JH 1-3), -11.13 ±1.98cm (JH 1-4) and -15.55±2.72cm (JH 1-5) for females. When expressed in percentage, these changes were, -20.28±4.65 (Rel. JH change 1-2), -37.25±6.68 (Rel. JH change 1-3), -47.86±6.34 (Rel. JH change 1-4), and -59.96±6.27 (Rel. JH Change 1-5) for males, and -13.65±3.73 (Rel. JH Change 1-2), -22.93±3.97 (Rel. JH Change 1-3), -31.94±4.67 (Rel. JH Change 1-4), and -44.33±4.75 (Rel. JH Change 1-5) for females.

Table 2.5 Jump Height

	Males	Females
JH 1	51.83±10.40	35.09±5.51
JH 2	41.31±8.44	30.33±5.16
JH 3	32.62±7.43	27.02±4.40
JH 4	27.16±6.71	23.96±4.65
JH 5	20.98±6.03	19.56±3.69

**Values expressed as means ± standard deviations in CM.*

Table 2.6 Ratio for each Trial

	Males	Females
Ratio 1 (cm·kg ⁻¹)	0.62±0.15	0.49±0.14
Ratio 2 (cm·kg ⁻¹)	0.40±0.09	0.36±0.10
Ratio 3 (cm·kg ⁻¹)	0.26±0.06	0.29±0.08
Ratio 4 (cm·kg ⁻¹)	0.19±0.05	0.24±0.06
Ratio 5 (cm·kg ⁻¹)	0.12±0.03	0.17±0.04

**Values expressed as means ± standard deviations.*

Figure 2.1 Male Correlation Figure

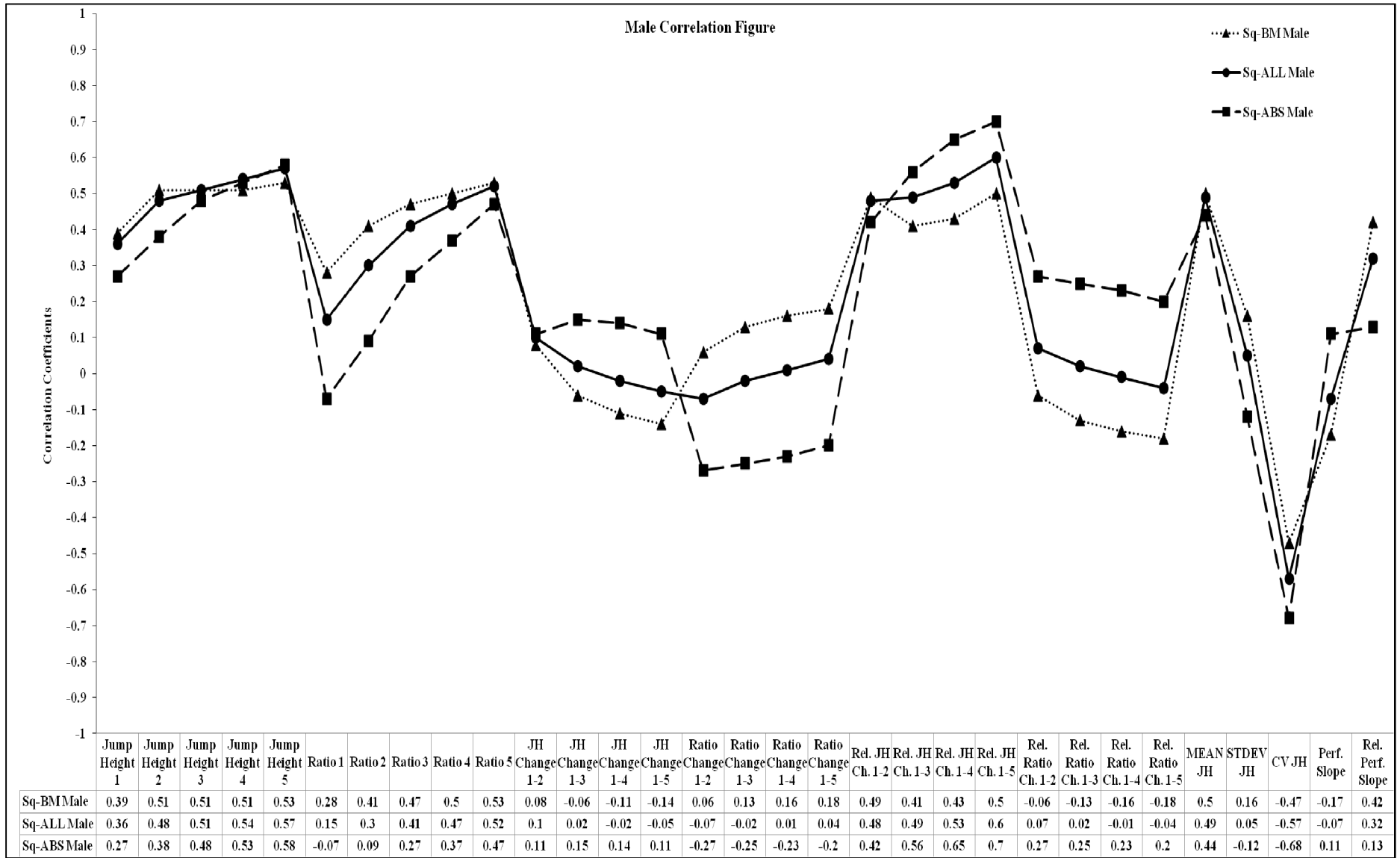
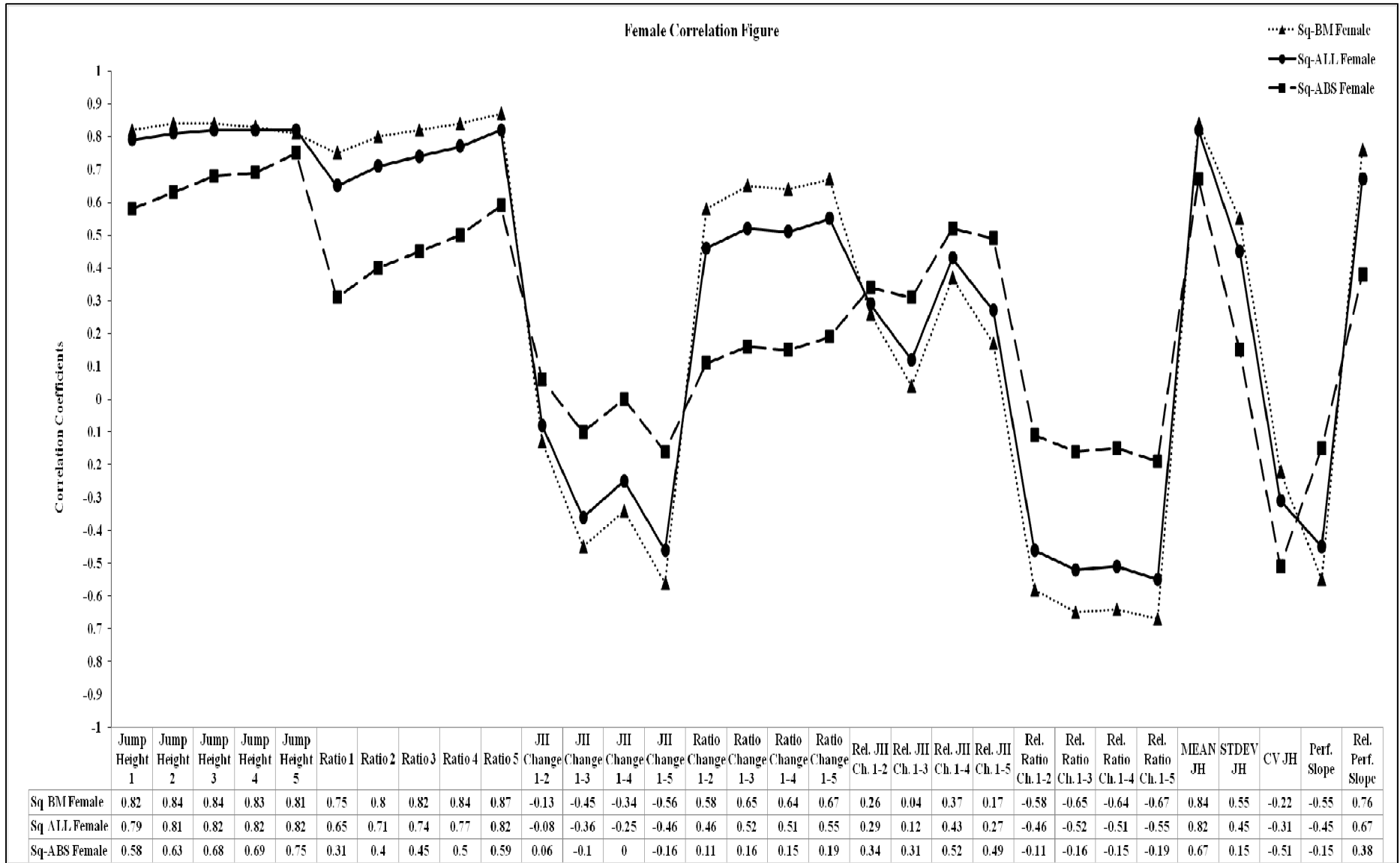


Figure 2.2 Female Correlation Figure



A very large correlation was produced between relative JH change 1-5 and absolute squat strength in the male data set (Figure 2.1). Large correlations existed between most jump heights and both absolute and relative squat strength and, the CV JH and Sq-ALL and Sq-ABS (Figure 2.1). Additionally, the Mean JH of all trials produced a large correlation with Sq-BM. In females, very large correlation coefficients existed between relative squat strength and all jump heights, almost all ratio measures, the Mean JH of all trials and the relative performance slope with Sq-BM in females (Figure 2.2). Large correlations existed between Sq-ABS and all jump heights, most ratio change measures and relative squat strength measures, the Mean JH of all trials and Sq-ABS, the STDEV JH and Sq-BM, the performance slope and Sq-BM and the relative performance slope with Sq-ALL (Figure 2.2).

DISCUSSION

The purpose of this investigation was to examine the relationship between estimated squat strength and variables from a static jump protocol considering its potential as a monitoring tool in collegiate strength and conditioning. This investigation was exploratory in nature. The major findings of this investigation were the overall sufficient reliability of measures of jump height, overall females' greater magnitudes of correlation coefficients than males', the large to very large correlation coefficients with jump heights, relative JH change from condition 1-5, CV JH, STDEV JH, mean JH, and both the relative and performance slopes, and, lastly, the differences in the absolute and relative squat strength estimates' relationship with the calculated variables.

The investigated protocol produced jump height measures that appear sufficiently reliable as revealed by ICC, CV, and effect sizes. As discussed in the methods section, the within condition difference in jump height was allowed to be ± 3 cm. (1.18in) to reduce the number of trials necessary to estimate a jump height for each condition. Previous studies investigating unweighted and weighted static jumps have reported similar reliability measures, although some investigations reported a smaller difference between jump trials than the current investigation (Carlock et al., 2004; Stone et al., 2003). For example, Kraska and colleagues reported ICC of 0.96-0.99 for static jump height in unweighted and weighted conditions (Kraska et al., 2009). Moir et al. reported CV ranging from 2.1%-2.6% for unweighted and weighted SJ height (Moir et al., 2005). Arteaga et al. reported CV values of 5.0-6.3% in SJ and Viitasalo reported 4.3-6.3% CV in SJ (Arteaga, Dorado, Chavarren, & Calbet, 2000; J. T. Viitasalo, 1988). Effect sizes were trivial, according to the criteria of Hopkins (Hopkins, 2002), in the current investigation for jump height (0.05-0.09). The trivial effect size indicated a minimal between-trial difference in jump height for each condition. Thus, the current protocol appears to be used reliable for practical settings.

Generally speaking, females' correlation coefficients were larger than males' coefficients. Thus, squat strength appears to be better inferred from SJ variables in female collegiate strength and explosive athletes compared to males. However, trends in correlation were similar between male and female variables. The difference in magnitude of correlation coefficients between males and females may be an artifact of the investigated subject pools. The female subject pool consisted solely of competitive Division 1 softball players while the male data set consisted of a variety of different athletes and some subjects not considered competitive athletes including sprinters, jumpers, weightlifters, ROTC cadets and student-volunteers. It is

possible that the greater heterogeneity in the male sample contributed to the difference in male and female correlation coefficient magnitude. Laffaye et al. (2014) noted differences in force-time variables between males and females when athletes competed in different sports were individually analyzed for correlations (Laffaye, Wagner, & Tomblason, 2014). However, further investigation is warranted to elucidate whether or not female collegiate strength and explosive athlete squat strength is more related to SJ variables compared to males.

Relative squat strength produced larger correlation coefficients with nearly all calculated variables in the female data set compared to Sq-ABS. A number of authors have reported similar findings between relative measures of strength and other mechanical measures, like peak power and RFD, and SJ variables (Carlock et al., 2004; Haff et al., 2005; Kraska et al., 2009; Stone et al., 2003). For example, Haff et al. (2005) reported similar findings that a ratio of peak force to body mass in isometric mid-thigh pull was better correlated to SJ height than absolute peak force ($r=0.75$ vs -0.16 and $r=0.63$ vs -0.37), in six elite women weightlifters (Haff et al., 2005). Furthermore, Kraska et al., reported slightly larger correlation coefficients between SJ height at 0kg and allometrically-scaled peak force in isometric mid-thigh pull ($r=0.47$), compared to absolute peak force ($r=0.40$) (Kraska et al., 2009). Hence, variables from SJ in general appear to be better correlated to relative squat strength and thus might be more useful in monitoring an athlete's training process compared to viewing these variables in relation to absolute squat 1RM alone.

Males' variables demonstrated a smaller difference in correlation coefficients between calculated variables and relative and absolute squat strength although, contrary to females' correlation coefficients, the largest correlation coefficients existed with Sq-ABS. Thus, calculated variables' relationships to absolute squat strength appear more pertinent in the male

data set. However, the differences in correlation coefficients between Sq-ABS and relative squat strength appear small. For example, coefficients between Sq-ABS and JH 1-5 ranged from 0.27-0.58 while Sq-ALL and Sq-BM coefficients ranged from 0.36-0.57 (Figure 2.1). As noted in the results section, each weighted condition's external load produced nearly the same percentages of absolute squat 1RM for males and females. Thus, the difference in the loads used between males and females is less likely to explain the largest correlation with Sq-ABS in males. One possible explanation is that male subjects with higher squat 1RMs had greater training ages and more experience with explosive exercise. Greater training age could have also meant that these male subjects were stronger and more explosive and thus were able to jump higher also. Other authors have reported subjects with more explosive resistance training experience and greater levels of maximum strength at the time of testing performed superiorly to weaker subjects in jump tests (Kraska et al., 2009; McBride et al., 1999). Furthermore, considering training backgrounds of male subjects, some of them reported concurrent training in training logs (i.e. ROTC cadets) characterized by a fairly equal split in training frequency between endurance-based activities and explosive resistance exercise, reporting roughly three days per week, on average, of up to three miles of running, while also resistance training three days per week up to one hour per session. Concurrent training has been reported to compromise strength and explosive training adaptations in addition to muscle hypertrophy (Wilson et al., 2012). Thus it is possible that male subjects who jumped poorly also had low Sq-ABS.

This investigation sought variables that could be used with high confidence to monitor changes in squat strength. Certain variables emerged with large to very large correlation coefficients to squat strength that warrant consideration. JH at each condition (JH 1-5) yielded large to very large correlations to both absolute and relative squat strength measures in females

(0.58-0.84). Very large correlations were demonstrated between the Mean JH of all valid trials with both absolute and relative squat strength (0.67-0.84) and between the relative performance slope and relative squat strength measures (0.67-0.76) in females. These correlation coefficients suggest that they can explain approximately up to 70% of the variance in absolute or relative squat strength in females, respectively. In males, JH at each condition yielded mostly large correlation coefficients to relative and absolute squat strength. Correlations ranged from 0.36-0.57 between the five jump heights and relative squat strength in males. Rel. JH change produced the largest correlation coefficients with relative and absolute squat strength ranging from 0.50-0.70. The Mean JH also yielded a large correlation (0.50) with Sq-BM. These correlation coefficients suggest that they can explain up to approximately 50% of the variance in absolute or relative squat strength in males, respectively. In practical settings, this implies a better probability of successfully inferring changes in an athlete's relative squat strength using these variables with large to very large correlations. Additionally, the difference between Sq-ALL and Sq-BM correlation coefficient appear similar in males while relative squat strength showed larger correlation coefficients in females. Hence, the use of relative squat strength may allow practitioners to monitor both female and male athletes. Furthermore, some similarities also existed between sexes affording the potential for practitioners to use the same variables for monitoring for both males and females. The five jump heights in both males and females produced mostly large to very large correlations to relative and absolute squat strength. Additionally, due to practically small differences in coefficients between JH 2, 3 and 4, it might be more practical to use only condition 1, 3 and 5 to reduce time constraints. Mean JH also produced a very large correlation with relative squat strength in females and a large correlation with relative squat strength in males, offering another potential monitoring tool for both sexes.

In conclusion, the current protocol produced reliable jump height for each condition, and large to very large correlation coefficients between certain SJ variables and squat strength measures. The current protocol appears to have potential to indirectly monitor changes in squat strength in collegiate strength /power sport athletes. However, this investigation used estimates of squat strength rather than actual measured squat 1RM. Future longitudinal investigations seeking to elucidate if changes in the aforementioned SJ variables are associated with concomitant increases in squat 1RM could help establish the validity of this protocol. Furthermore, future work could further clarify a difference in relationships to squat strength between males and females and examine if different variables are more specific to certain sports compared to other variables. Currently, five jump heights and mean JH are suggested by the authors to offer reasonable variables for monitoring purposes in the practical setting to indirectly monitor changes in squat strength. Rel. JH change produced a very large correlation to Sq-ABS but failed to produce above moderate correlation coefficients in females, suggesting its limited practicality to use for both sexes. Furthermore, the relative performance slope produced very large correlations in females but failed to do so in males, suggesting its limited practicality to use for both sexes. Thus, five jump heights and mean JH seem to offer a better practical option for practitioners given the similarity of coefficient magnitude in both sexes. In the Appendix section of this paper, suggested variables to calculate via Microsoft Excel® and how to calculate them is provided for implementation of this protocol in the practical setting.

PRACTICAL APPLICATIONS

The nature of 1RM testing generates a relatively high amount of fatigue and can be time consuming in the practical setting. Furthermore, due to the lack of a standardized model to

accurately assess 1RM in the back squat, 1RM testing can also tend to be inaccurate if missed attempts with supra-maximal loads precede made attempts at a lower weight, perhaps revealing an invalid 1RM due to fatigue from the missed attempt. An alternative testing method such as the current SJ protocol might be more effective for more regular monitoring, while integrating 1RM testing strategically at appropriate times. This investigation produced a large number of variables. However, for practicality, investigators suggest that the variables JH and mean JH appear to offer the best practical options to indirectly monitor changes in squat strength and yield insight into other pertinent training adaptations. All variables can be calculated via Microsoft Excel. (See Appendix for calculations.)

APPENDIX

Suggested Variable Calculations for Monitoring Purposes

- 1) Create a mean jump height for each condition ,1-5, based on two trials within 3 cm. of one another titled: JH1, JH 2, JH 3, JH 4, JH 5; from jump heights collected via contactmat data. The JustJump® contactmat was used in this investigation and yielded reliable measures.
- 2) Ensure to collect the athlete's body mass before the testing session and calculate a "system mass" (i.e. body mass + external load) for each condition titled SM 1, SM 2, SM 3, SM 4, SM 5.
- 3) Calculate the difference between each jump height and system mass for each trial between the given trial and trial 1 (i.e. Trial 1-Trial 2= Difference, Trial 1-Trial 3=Difference, etc.) titled: JH Change (1-2, 1-3, 1-4, 1-5) and SM Change (1-2, 1-3, 1-4,1-5).

4) By using the difference values for each condition, calculate a percent difference between the given trial and trial 1 for both jump heights and system masses. (i.e. Trial 1-Trial 2=Difference, Difference divided by Trial 1= Value, Value x 100= %) titled relative JH change and relative SM change.

5) From these relative differences, one can use the SLOPE function in Microsoft Excel to create a slope with relative JH change variables on the y-axis and relative SM change variables on the x-axis. If the slope value is created and recorded for each testing session, given the large correlation coefficients to squat strength in this investigation, the strength and conditioning professional can see that when the slope value begins to become more positive, the athlete is hypothetically becoming relatively stronger in the back squat. Also, a figure can be created in Excel to visually depict the changes in slope over time for explanation to the athlete or visual representation to the strength and conditioning professional.

6) Calculate a “MEAN JH” for all trials, by using the calculated mean jump heights for each condition, with the AVERAGE function in Microsoft Excel. Basically, given the large correlation coefficients with measures of squat strength in the study, as the MEAN JH increases from testing session to testing session, one can infer hypothetical, concomitant increases in squat strength.

These data can potentially be used, in addition to 1RM testing, to supply desirable data to the strength and conditioning professional and offer the capability of further inference into adaptations to the training process above solely using 1RM testing data or bodyweight vertical jump testing data alone.

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CHAPTER 4

SUMMARY AND FUTURE INVESTIGATIONS

The purpose of this thesis was to examine the relationship between estimated squat strength and variables from a static jump protocol considering its potential as a monitoring tool in collegiate strength and conditioning. As an experimental approach to the purpose, forty-one young, healthy, and mostly currently competitive Division 1 athletes reported estimated squat 1RM and completed a static jump protocol. This investigation was exploratory in nature, being the first of its kind to examine the potential of a static jump protocol to indirectly monitor changes in squat strength in collegiate strength and explosive athletes. Correlations were produced between a number of variables using jump height and system mass and both relative and absolute squat strength estimates in order to identify variables showing high confidence to potentially indirectly monitor changes in squat strength in the practical setting. As previously discussed, the investigated protocol considered the potential to allow more regular monitoring of changes in squat strength, compared to 1RM tests inducing relatively higher amounts of fatigue and consuming greater amounts of already limited time in the practical setting. The investigated protocol has potential to afford the opportunity to devote more time to an actual training session or sport practice while still providing pertinent adaptation data to the practitioner.

Monitoring the training process affords the practitioner important capabilities ultimately related to performance. Three prominent affordances emerging from the scientific literature are: 1) the ability to control the development of unnecessary amounts of fatigue during different phases of the training plan and competitive season, 2) the ability to adjust training variables appropriately to promote optimal training adaptations and performance preparations (e.g. peaking), and 3) monitoring offers an objective lens through which to view training, recovery

and coaching interventions for their effectiveness (Banister & Calvert, 1980; Bompa & Haff, 2009; Issurin, 2009; Medvedyev, 1986; Olbrecht, 2000; Sands & McNeal, 2000; Sands & Stone, 2005; Siff & Verkhoshansky, 2004; Smith, 2003; Stone et al., 2007). Currently, the literature suggests the 1RM back squat test as the gold standard for monitoring maximum lower body strength in the practical setting, while countermovement jumping has also been reported a popular test intending to examine and monitor adaptations to training (Baechle & Earle, 2008; Bazyler, 2013; Bompa & Haff, 2009; Taylor, 2012). However, 1RM testing for monitoring purposes is considered to induce high amounts of fatigue and can consume appreciable time potentially allocated to an actual training session or sport practice, compared to less time-consuming, less-invasive methods of testing like vertical jump testing (Baechle & Earle, 2008; Bazyler, 2013; Moir et al., 2005; Moir et al., 2008; Taylor, 2012; Willardson & Burkett, 2006). Furthermore, as previously argued by the author, unweighted vertical jumping is inadequate when seeking to infer maximum strength adaptation considering the intensity of the unweighted condition, compared to an actual 1RM test or loaded jumping. Considering findings of other investigators reporting large correlations between strength and static jump variables (Carlock et al., 2004; Haff et al., 2005; Kraska et al., 2009; Stone et al., 2003), this investigation sought to explore the potential of a static jump protocol to indirectly monitor changes in squat strength in a less time-consuming, less invasive manner; compared to more regular 1RM testing. For example, Stone and colleagues (Stone et al., 2003) investigated relationships between maximum strength and peak power in CMJ and SJ with loads ranging from 0 to 100% of self-reported squat 1RM. Static jump peak power had larger correlations ($r=0.75-0.94$) to static squat jump 1RM at every loading condition compared to CMJ related dynamic 1RM ($r=0.60-0.88$). Other authors have

also reported larger correlations between variables of SJ and measures of strength and explosiveness compared to CMJ (Carlock et al., 2004; Haff et al., 2005; Kraska et al., 2009).

The investigated protocol seemingly affords the practitioner a means of more regular monitoring of squat strength adaptation compared to regular 1RM testing, while also providing insight into jump ability and adaptations thereof. Other tests, like sprint speed tests and tests seeking to evaluate agility, differ in intent compared to the intent of tests like the 1RM back squat, the investigated SJ protocol, and other tests intending to measure or monitor changes in strength, specifically. Thus, when ranking tests in order of importance or selecting tests to evaluate performance characteristics or adaptations to training, the intention of said tests are a necessary consideration when ultimately interpreting test results and drawing conclusions about specificity to sport performance and training adaptations. In that many strength and explosive sports involve sprinting, jumping, and regular, rapid change of direction; certain other tests seeking to evaluate these skills, specifically, warrant consideration as separate tests beyond maximum strength assessments alone as they are inherently different. As noted by Stone et al, some important considerations regarding test selection specificity to sport are: 1) movement pattern specificity 2) force magnitude (average and peak force similarity to sport performance tasks 3) Rate of force development (average and peak) 4) acceleration and velocity parameters and 5) ballistic versus nonballistic movements (Stone et al., 2007, p. 171). Other authors have demonstrated increases in measures of strength after 6-10 weeks of training interventions, warranting consideration of 1RM testing or tests monitoring changes in strength approximated to these time frames (Bompa & Haff, 2009; Buresh et al., 2009; Narici et al., 1989; Stone et al., 2007). Possibly every 10 weeks, given the time frames associated with changes in strength by other authors, may be a reasonable time frame to conduct 1RM testing considering the relatively

high amount of fatigue generation and allocation of appreciable time in larger-sized teams (Bompa & Haff, 2009; Buresh et al., 2009; Narici et al., 1989; Stone et al., 2007). Alternatively, the investigated SJ protocol may provide a means to more regular testing, possibly every 4-6 weeks, considering the employment of submaximal loads, relatively lower amount of fatigue generation and lower amount of time consumed in teams with a large number of athletes in comparison with 1RM testing.

However, in that 1RM testing is a more direct measure of maximum strength, compared to the investigated protocol employing submaximal percentages of estimated maximum squat strength and offering an indirect method of monitoring changes in squat strength; the investigated protocol is not intended or suggested to holistically replace 1RM testing. Currently, strategic placement of 1RM testing in coordination with the training plan of athletes seemingly offers the best practical method of measuring lower body maximum strength adaptation in the practical setting in comparison with the investigated protocol, considering that it is a more direct measure of maximum strength, employing perceived maximum loads (Baechle & Earle, 2008; Bazyler, 2013). In conclusion, given the reliability of jump height measures in the investigated static jump protocol comparable to other studies examining vertical jump height (Arteaga et al., 2000; Kraska et al., 2009; Moir et al., 2005; J. T. Viitasalo, 1988) and the production of large correlation coefficients between mean JH and JH's 1-5 with squat strength estimates, the current protocol seemingly offers a means of more regular monitoring in the practical setting. Future longitudinal investigations seeking to elucidate if changes in the aforementioned SJ variables are associated with concomitant increases in squat 1RM could help establish the validity of this protocol. Furthermore, future work could further clarify a difference in relationships to squat strength between males and females and examine if different variables are more specific to

certain sports compared to other variables. Additionally, future work could help establish the usefulness of this protocol and variables thereof for fatigue monitoring purposes.

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APPENDICES

Appendix A: Institutional Review Board Approval



EAST TENNESSEE STATE
UNIVERSITY

Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707
Phone: (423) 439-6053 Fax: (423) 439-6060

IRB APPROVAL – Initial Expedited Review

January 8, 2015

Cody Haun

Re: The Relationship Between Weighted Static Jump Height Dropoff and Estimated Back Squat 1RM:
A Potential Protocol to Monitor Training Adaptations.

IRB#: c1214.14s

ORSPA #: n/a

The following items were reviewed and approved by an expedited process:

- xform New Protocol Submission; Informed Consent Document (version 11/19/2014, stamped approved 1/7/2015); Data Collection Sheet; CV

On **January 7, 2015**, a final approval was granted for a period not to exceed 12 months and will expire on **January 6, 2016**. The expedited approval of the study will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved Informed Consent Documents** have been stamped with the approval and expiration date and these documents must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document (version 11/19/2014, stamped approved 1/7/2015)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

Projects involving Mountain States Health Alliance must also be approved by MSHA following IRB approval prior to initiating the study.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.



Accredited Since December 2005

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,
Stacey Williams, Chair
ETSU Campus IRB

cc:

Appendix B: Informed Consent

PRINCIPAL INVESTIGATOR: _____ Cody Haun _____

TITLE OF PROJECT: The Relationship Between Weighted Static Jump Height Dropoff and Estimated Back Squat 1RM: A Potential Protocol to Monitor Training Adaptations

Informed Consent Form

Introduction:

This Informed Consent will explain about you being a participant in a research study. It is important that you read this material carefully and then decide if you wish to be a volunteer.

Purpose:

The purposes of this study are to estimate power production and observe the effect of various loads on static jump height in relation to a subject's estimated 1-Repetition Maximum (1RM) back squat.

DURATION:

You will take part in one combined familiarization and data collection session taking approximately 45 minutes.

PROCEDURES:

1. Reporting of an estimated 1RM in the Barbell Back Squat based on the most recent training block using the Epley Formula.
2. Collection of anthropometrics (Height and Body Mass)
3. Warm-Up Protocol consisting of 25 Jumping Jacks, A Bodyweight Jump @ 50% perceived maximal effort. A Bodyweight Jump @ 75% perceived maximal effort and a final body weight warm up jump @100% perceived maximal effort. The final warm up jump will be a 75% perceived maximal effort jump with the opening load of the subject. (PVC Pipe) First Weighted Jumps will be: 45lbs for male and 28lbs for female
4. *Testing Protocol: Two jumps will be performed using each load:
 - a. Women: 0, 28, 45, 65, 95 lbs.
 - b. Men: 0, 45, 95, 135, 185 lbs.

*Subjects will rest for approximately 30-45 seconds in-between jumps.

*(Some jumps may be video recorded for educational purposes and use in presentation of data in scholarly works or at conferences; by participating, you are acknowledging this and are permitting the sharing/presentation of this data.)

ALTERNATIVE PROCEDURES/TREATMENTS:

There are no alternative procedures except not to participate in the study.

APPROVED
By the ETSU IRB

DOCUMENT VERSION EXPIRES

Ver. 1/24/15 **JAN 26 2015** Page 1 of 3 **JAN 06 2016** Subject Initials _____

tsy
Chair-IRB Coordinator

ETSU IRB

PRINCIPAL INVESTIGATOR: Cody Haun

TITLE OF PROJECT: The Relationship Between Weighted Static Jump Height Dropoff and Estimated Back Squat 1RM: A Potential Protocol to Monitor Training Adaptations

POSSIBLE RISKS/DISCOMFORTS:

There is negligible risk of injury as a result of participation in this study. The researchers will teach proper technique in performing the jumps and proper landing technique in the familiarization session; to reduce the risk of injury we are not requiring an actual 1-RM back squat. Loads used in this study are submaximal loads used frequently by the subjects in weight training activities. To further reduce the risk of injury, metal stops will be used as a safety measure in case you drop the weight during a jump.

POSSIBLE BENEFITS:

Benefits from this study include free muscular power and jump height assessment by certified strength and conditioning specialists (NSCA-CSCS). Findings from the study will provide you information on your jump height under various loads during static jumps and estimated power production during these jumps. These results can be used as baseline data for monitoring of adaptations to training.

COMPENSATION FOR MEDICAL TREATMENT:

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

FINANCIAL COSTS:

There are no financial costs to you.

COMPENSATION IN THE FORM OF PAYMENTS TO RESEARCH PARTICIPANTS:

There is no compensation for your participation in this research.

VOLUNTARY PARTICIPATION:

Participation in this research experiment is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. Your decision about participating will not negatively affect your grades for any courses you are taking or plan to take in the exercise science department taught by any sport science staff. You may quit by calling or e-mailing Cody Haun at 423-426-4439, haunct@goldmail.etsu.edu.

CONTACT FOR QUESTIONS:

DOCUMENT VERSION EXPIRES _____

Ver. 1/24/15

APPROVED
By the ETSU IRB
JAN 26 2015
by _____
Chair/IRB Coordinator

Page 2 of 3

JAN 06 2016

Subject Initials _____

ETSU IRB

PRINCIPAL INVESTIGATOR: Cody Haun

TITLE OF PROJECT: The Relationship Between Weighted Static Jump Height Dropoff and Estimated Back Squat 1RM: A Potential Protocol to Monitor Training Adaptations

If you have any questions, problems or research-related injury or medical problems at any time, you may call or e-mail Cody Haun at 423-426-4439, haunct@goldmail.etsu.edu. You may call the Chair of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423-439-6055 or 423-439-6002.

CONFIDENTIALITY:

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in a locked file cabinet in the kinesiology lab (Minidome 113) for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the ETSU IRB and the Exercise and Sport Science Department will have access to the study records.

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

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

APPROVED
By the ETSU IRB
JAN 26 2015


DOCUMENT VERSION EXPIRES
JAN 06 2016
ETSU IRB

VITA

CODY TAYLOR HAUN

- Education: M.A. Kinesiology and Sport Studies
East Tennessee State University, Johnson City, TN, 2015
B.S. Physical Education, Exercise Science
East Tennessee State University, Johnson City, TN, 2013
David Crockett High School, Telford, TN, 2009
- Professional Experience: Assistant Strength and Conditioning Coach
East Tennessee State University, 2013-2015
Graduate Assistant
East Tennessee State University, 2013-2015
Personal Trainer and Assistant Manager
Cor24 Community Fitness, Gray, TN, 2013-2014
Personal Trainer
BCPA, East Tennessee State University, 2012-2013
- Professional Certifications: NSCA Certified Strength and Conditioning Specialist, 2013
American Heart Association CPR/AED, 2012
- Abstracts: A Comparison of Baseball and Softball Players' Bilateral Strength
Asymmetry and Its Relationship with Performance.
Proceedings of the Eighth Annual Coaches and Sport
Science College, Johnson City, TN, Dec. 5-7, 2013.
Christopher Bailey, Timothy J. Suchomel, George K.

Beckham, Timothy C. McInnis, Austin R. Driggers, **Cody T. Haun**, Kimitake Sato, and Michael Stone

Utilizing Weightlifting for Road Cycling Performance.

Proceedings of the Ninth Annual Coaches and Sport Science College, Johnson City, TN, Dec. 12-13. Nicholas J. Fiolo, Christopher B. Taber, Caleb D. Bazylar, **Cody T. Haun**, Robert Duncan, Aaron Thomas, Michael W. Ramsey, and Michael Stone.

Honors and Awards: Outstanding Service and Dedication to the University Award
ETSU Disability Services, May 2014

ETSU Cum Laude, May 2013

ETSU Dean's List, 2010, 2012-2013

Professional Conferences Attended:

International Society of Biomechanics in Sport Conf., Jul. 2014

NSCA Southeast Regional Conference, April 2014

ETSU Coaches and Sport Science College, December 2014

ETSU Coaches and Sport Science College, December 2013