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Effects of Eccentric Contraction Duration on Muscle Strength, Power Production, Vertical Jump and Soreness

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THE EFFECTS OF ECCENTRIC CONTRACTION DURATION OF MUSCLE STRENGTH, POWER PRODUCTION, VERTICAL JUMP AND SORENESS

By

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DISSERTATION

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Abstract

Prior research has investigated the effects of either eccentric-only training or comparing eccentric and concentric exercise on changes related to strength and power expression, but no research to date has investigated the impact of altering the duration of either the concentric or eccentric component on these parameters. Therefore, the purpose of this study was to assess the duration of eccentric (i.e. 2-second, 4-second vs. 6-second) muscle contractions and their effect on muscle strength, power production, vertical jump and soreness using a plate-loaded barbell Smith squat exercise. Thirty college-aged males (23 ± 3.5 years, 178 ± 6.8 cm, 82 ± 12 kg and 11.6 ± 5.1 % fat) with 3.0 ± 1.0 years of resistance training experience and training frequency of 4.3 ± 0.9 days per week were randomized and assigned to one of three eccentric training groups that incorporated different patterns of contraction. For every repetition, all three groups utilized two-second concentric contractions and paused for one second between the concentric and eccentric phases. The control group (2S) utilized two-second-eccentric contractions while the 4S group performed four-second eccentric contractions and the 6S performed six-second eccentric contractions. All repetitions were completed using the barbell Smith squat exercise. All participants completed a four-week training protocol that required them to complete two workouts per week using their prescribed contraction routine for 4 sets of 6 repetitions at an intensity of 80 – 85% 1RM. Two-way mixed factorial ANOVA were used to determine changes among groups. A p-value of 0.05 was used for all statistical determinations. At baseline, no between-group differences ($p > 0.05$) were found for any anthropometric, 1RM or dietary data with the exception of absolute protein intake ($p = 0.03$). For all performance data, significant group x time interaction effects were found for average power production across all three sets of a squat jump protocol ($p = 0.04$) while vertical jump did not reach significance but there was a trend towards a difference (GxT, $p = 0.07$). No other significant ($p > 0.05$) group x time interaction effects were found for the performance variables. All groups showed significant main effects for time in 1RM ($p < 0.001$), vertical jump ($p = 0.004$), peak power ($p < 0.001$) and average power ($p < 0.001$). Peak velocity data indicated that the 6S group experienced a significant reduction in peak velocity during the squat jump protocol as a result of the 4-week training program ($p = 0.03$). Soreness data revealed significant increases across time in all groups at both week 0 and week 4. Paired sample t-tests revealed greater differences in soreness values across time in the 2S group. The results provide further evidence that resistance training with eccentrically dominated movement patterns can be an effective method to acutely increase maximal strength and power expression in trained college age men. Furthermore, longer eccentric contractions may negatively impact explosive movements such as the vertical jump while shorter eccentric contractions may

instigate greater amounts of soreness. These are important considerations for the strength and conditioning professional to more fully understand that expressions of strength and power through eccentric training and varying durations of eccentric activity can have a significant impact for populations ranging from athletes desiring peak performance.

Table of Contents

List of Figures:……………………………………………………………………..**xi**

List of Tables:………………………………………………………………………**xiii**

Symbols/ Abbreviations:……………………………………………………………..**xiv**

CHAPTER 1:

Introduction…………………………………………………………………1

Problem Statement…………………………………………………………..3

Purpose of Study…………………………………………………………….4

Hypotheses…………………………………………………………………..5

Scope of Study………………………………………………………………....5

Assumptions…………………………………………………………………...6

Limitations……………………………………………………………………6

Significance of the Study……………………………………………………...7

Definition of Terms…………………………………………………………...7

References…………………………………………………………………….8

CHAPTER 2: REVIEW MANUSCRIPT

How to Incorporate Eccentric Training Into an Eccentric Program

Abstract………………………………………………………………………14

Introduction…………………………………………………………………..15

Benefits of Eccentric Training……………………………………………….18

Incorporating Eccentrics Into Your Program……………………………...21

Scenario1……………………………………………………………………..25

Scenario 2…………………………………………………………………….26

Conclusions……………………………………………………………………..28

Acknowledgments……………………………………………………………29

References……………………………………………………………………30

CHAPTER 3 RESEARCH MANUSCRIPT

Abstract……………………………………………………………………42

Introduction……………………………………………………………………..44

Methods…………………………………………………………………….....46

Subjects……………………………………………………………………48

Procedures………………………………………………………………………50

Eccentric Exercise Protocol…………………………………………….50

Nutritional Control……………………………………………………...51

Body Composition and Anthropometry…………………………………...51

One Repetition Maximum (1RM) Testing……………………………..52

Power Production and Testing……………………………………………53

Perceived Soreness……………………………………………………..54

Vertical Jump…………………………………………………………..54

Statistical Analysis……………………………………………………..55

Results………………………………………………………………….55

Discussion………………………………………………………………...58

Practical Applications…………………………………………………….68

Acknowledgements…………………………………………………70

References……………………………………………………………….71

CHAPTER 4: SUMMARY, RECOMMEDNATIONS, AND FUTURE STUDIES

Summary……………………………………………………………………82

Recommendations…………………………………………………………..83

Future Studies………………………………………………………………84

References………………………………………………………………....87

Appendix A………………………………………………………………...88

Appendix B………………………………………………………………...94

Appendix C………………………………………………………………...96

Appendix D………………………………………………………………...99

Appendix E………………………………………………………………...100

Appendix F………………………………………………………………...101

Appendix G………………………………………………………………102

LIST OF FIGURES

CHAPTER 2: REVIEW MANUSCRIPT

FIGURE 1: Starting position of single leg stiff-legged deadlift (SLDL). Athlete should strive to stay arched as much as possible while driving the back leg up with hip extended, and use a slight knee bend in the front leg. There should be little hip rotation.

FIGURE 2: Finish position of single-leg stiff-legged deadlift (SLDL).

FIGURE 3: Starting position of glute/ham Raise: Athletes should place their feet against the footplate in between the rollers as they lie facedown. The knees should be just behind the pad. Incorporating the eccentric emphasized technique(s), the athletes should start from the top of the movement. Keep your body straight and stay braced with the core. Slowly move down focusing on the eccentric portion while keeping upper body straight, and continue until you are fully extended.

FIGURE 4: Mid-position of glute/ham Raise

FIGURE 5: Finish position of glute/ham Raise

FIGURE 6: Starting position of eccentric pull-up using a supinated grip. The athletes can also use various grip positions such as double overhand, neutral, narrow, or wide.

FIGURE 7: Mid-position of eccentric pull-up

FIGURE 8: Finish position of eccentric pull-up

FIGURE 9: Starting position of barbell hip thrust. The bar should be positioned in the crease of the hip with the hands holding the bar into position throughout the movement so the bar does not move forwards or backwards.

FIGURE 10: Top position of barbell hip thrust. At the top, the hips should be fully extended, with the shins vertical. The athletes should complete the lift by contracting the glutes hard and pushing the hips forward. The low back should not be overextended. At the top of the movement your torso should be parallel to the ground.

FIGURE 11: Top position with leg elevated of barbell hip thrust. Athlete should strive to keep the lifted leg perpendicular to ground through movement for balance and added core stability.

FIGURE 12: Middle position with leg elevated of barbell hip thrust (downward motion).

FIGURE 13: Finish position of barbell hip thrust.

CHAPTER 3 RESEARCH MANUSCRIPT FIGURES

Figure 1: Pre and Post values for one repetition maximum (kgs) for all groups……………………………………………………………………………….75

Figure 2: Perceived soreness levels for the 2S group ……………………………...76

Figure 3: Perceived soreness levels for the 4S group……………………………....77

Figure 4: Perceived soreness levels for the 6S group……………………………....78

LIST OF TABLES

CHAPTER 2: REVIEW MANUSCRIPT

Table 1: Eccentric Emphasized Exercises- Upper and Lower Body………………35

Table 2: Eccentric Training Techniques…………………………………………...37

CHAPTER 3 RESEARCH MANUSCRIPT

Table 1: Descriptive statistics for all study participants…………….……………..79

Table 2: Training progression for all workouts, sets……………...……………….80

Table 3: 1RM, vertical jump, peak power, peak velocity and average power values……………………………………………………………………………….81

SYMBOLS/ABBREVIATIONS

≥: greater than or equal

≤: less than or equal

±: plus-minus sign

2S: 2-second

4S: 4-second

6S: 6-second

1RM: one repetition maximum

ANOVA: analysis of variance

BM: body mass

cm: centimeter

day/week: days per week

g/d: grams per day

kg: kilogram

m/s: meters per second

n: subject number

std: standard deviation

W: watts

Chapter I

<u>Introduction</u>

Human locomotion, irrespective of the setting in which it occurs or its purpose depends largely upon muscle activation and the forces produced as part of this activation. Among other factors, the resulting action depends to a great extent on both those forces applied to the body as well as the forces produced by the body. Dynamic muscular contractions can be characterized by two primary actions, concentric and eccentric contractions. A concentric contraction results in muscle shortening and occurs when the force produced during a contraction exceeds the force applied to the muscle. Alternatively, an eccentric contraction occurs when the muscle is forcibly lengthened or elongated. An eccentric contraction results when the force produced inside the muscle is less than what is applied to the muscle externally (5) and results in active lengthening of the muscle fibers under some level of load. When compared to concentric actions, eccentric muscle actions are able to produce greater amounts of force with some studies reporting that eccentric strength levels may be 20 – 60% higher than concentric strength levels within the same research subjects (16). Interestingly, researchers routinely report that lower levels of neural activation (8, 15, 32) occur during eccentric contractions when compared to concentric efforts providing some level of indication that typical loading patterns used as part of resistance exercise prescriptions might be dependent upon the muscle actions involved. In addition to force production dynamics and neural contributions, additional literature indicates that acute bouts of eccentric contractions elicit greater muscle damage compared to concentric training (27, 28), which is commonly assessed by evaluating changes in force production, self-reported soreness and serum levels of creatine kinase (20, 35, 36). Moreover, a recent review suggests that some level of damage may be needed to facilitate other adaptations such as muscle hypertrophy (30), which supports the need to better understand how manipulations of eccentric contractions may impact resulting physiological adaptations.

Eccentric resistance training incorporating submaximal, maximal (100% 1RM) or supramaximal (> 100% 1RM) training loads have been shown to stimulate greater increases in maximal muscle strength (15, 17, 18, 26, 31), compared to conventional types of strength training (6)), or using very light loads (3). While both concentric and isometric muscle contractions elicit a hypertrophy response, numerous studies have reported that eccentric actions may have the greatest effect on skeletal muscle growth (14, 18, 19, 25, 29). Importantly, some studies go one step further and indicate that the speed of the eccentric contraction may have a predominant influence over the hypertrophy that results (11, 34). Thus from a hypertrophy perspective, it appears that movement speed during the eccentric portion of a repetition may play a significant role in determining how the involved muscle responds.

When looking closely at the impact of contraction speed, most work has centered upon the entire eccentric-concentric contraction of varying speeds with little to no work focused upon the specific impact of altering the contraction speed and/or duration of only part of the contraction cycle (concentric only or eccentric only). In this respect, resistance training regimens that involve a rapid production of force can impact changes in the rate of force development (RFD) and resulting power production (24). Increases in power production have been shown to result from slower-speed training along with increases in agonist muscle activation (1). For example, Blazevich (2) examined the effects of slow-speed resistance training involving concentric versus eccentric contraction on contractile rate of force development (RFD) involving isometric knee extension. They found that subjects with a lesser ability to rapidly attain their maximum force before training improved RFD with slow-speed resistance exercise (2). Furthermore, a meta-analysis by Roig (29) compared the effectiveness of exercise modalities at eliciting muscular adaptations. Roig summarized that high-intensity eccentric training was associated with greater muscular adaptations than concentric training, but the impact of changing the duration of the eccentric contractions remains undetermined. Finally, many studies have employed isokinetic dynamometers to execute the isokinetic eccentric actions. While valuable for their ability to control the contraction speed, laboratory-based isokinetic measurements are expensive, lack portability and typically only employ single-joint muscle actions (e.g., knee extension or elbow flexion) that are difficult to replicate to real-world resistance training situations. Therefore, the purpose of this study is to examine the impact of four weeks of eccentric training at a load equivalent to 80% 1RM using different durations of eccentric contractions using a commercially available Smith machine squat rack and to determine the changes in muscle strength, power production, vertical jump and soreness.

Problem Statement

Prior research has investigated the effects of either eccentric-only training or comparing eccentric and concentric exercise on changes related to strength and power expression, but to date has investigated the impact of different durations of the eccentric contraction. The purpose of this investigation will assess the effect of eccentric contraction duration on changes in muscle strength, power production, vertical jump and soreness. Considering that prior research has demonstrated positive outcomes of eccentric exercise training, this topic permits examination of the role of different eccentric contraction durations during resistance training and exercise performance.

Purpose of the Study

The purpose of this study is to assess the duration of eccentric (i.e. 2-second, 4-second vs. 6-second) muscle contractions and their effect on muscle strength, power production, vertical jump and soreness using a plate-loaded barbell Smith squat exercise.

Hypothesis

The following hypothesis were tested in this study:

Null Hypothesis: There will be no differences that result from performing eccentric contractions of varying durations relative to changes in muscle strength, power production, vertical jump and soreness.

Alternative Hypothesis 1: Strength will significantly ($p<0.05$) increase when eccentric training is completed in a duration-dependent manner when compared to a control group (2-second).

Rationale: Eccentric training has demonstrated effectiveness in improving greater gains than concentric muscular strength using both upper and lower body exercise. (4, 15, 19, 25)

Alternative Hypothesis 2: In a duration-dependent manner using eccentric contractions, indicators of soreness will significantly increase ($p< 0.05$) in comparison to a control group (2-second).

Rationale: Levels of soreness from eccentric training are linked to mechanical disturbance of the actomyosin bond versus ATP-dependent detachment, resulting in greater tension on the contractile unit (10).

Alternative Hypothesis 3: In a duration-dependent manner using eccentric contractions, power production and vertical jump will be significantly increased ($p < 0.05$) in comparison to a control group (2-second).

Rationale: It has been reported that the peak force produced during eccentric muscle actions is significantly greater than that produced during other muscle contractions (7, 9)

Scope of the Study

Approximately 30 healthy, recreationally trained males between the ages of 18-30 years old were used to determine the impact of different durations of eccentric contractions as part of a four week resistance-training program on changes in muscle strength, power production, vertical jump and soreness. As part of the four-week eccentric training period, participants completed a total of eight workouts (2 workouts per week) consisting of four sets of six repetitions using a plate-loaded Smith squat exercise with intensity equivalent to 80-85%1RM. Three minutes rest was provided between each set. The control group utilized a standard lifting cadence (2-s eccentric, 1-s pause, 2-s concentric). The other two groups completed identical workouts (4 sets x 6 reps @ 80-85% 1RM), but one group incorporated a four-second eccentric contraction and the third and final group completed six-second eccentric contractions. All repetitions were supervised by trained investigators and performed using a full range of motion using the squat exercise (approximately 80 – 90° of motion). Before and after completion of this training program, participants had their muscle strength, power production, vertical jump and soreness measured to determine the impact of different eccentric contraction durations on the above-mentioned parameters.

Assumptions

The following assumptions were made in this study:

1). Participants abstained from medications and avoided changes in their diet throughout the study and avoided caffeine 12 hours prior to each exercise test.

2). All participants refrained from any training of the lower body outside of the supervised training for the duration of the study.

3). The participants exerted maximal effort for each resistance training session.

Limitations

The following limitations were identified for this study:

1. The study group consisted of healthy, recreationally trained male subjects in the age range of 18 to 30 years old. Therefore, the results can only be generalized to a healthy, recreationally trained population of similar age.

2. Our measure of muscle strength is the Smith squat exercise, which is a movement that may not extrapolate well to other sports-related activities.

3). Our measured changes of muscle strength, power production, vertical jump and soreness are limited only to the measurement times outlined in this protocol.

Significance of the Study

This study examined the impact of changing the duration of eccentric contractions and comprehensively examined outcomes associated with performance, muscle strength, power production, vertical jump and soreness. No prior investigation has assessed the effects of eccentric contraction duration and in particular with respect to muscle strength, power production, vertical jump and soreness. Outcomes from this study will expand the knowledge and understanding of the endogenous adaptations made in response to eccentric training and whether altering the prescription of eccentric training exerts any impact over these adaptations. The use of eccentric exercise also has important implications by reducing the likelihood of injury and re-injury throughout the rehabilitation process (21), those with tendiopathies (22, 23, 33), and ACL rehabilitation (12, 13)

Definition of Terms

The terms in this study have been defined as follows:

Adenosine triphosphate (ATP): A multifunctional nucleotide that transfers chemical energy within cells for metabolism. It is the major energy currency molecule of the cell.

Concentric Muscle Action: When the force produced by the muscle exceeds the force applied to the muscle, the muscle will shorten. This is known as muscle shortening.

Creatine Kinase: An enzyme expressed by various tissues and cell types used in the rapid buffering and regeneration of ATP via creatine phosphate hydrolysis and ADP.

Eccentric Muscle Action: Eccentric contractions describe muscle elongation, or the active lengthening of muscle fibers under load.

Delayed-Onset Muscle Soreness (DOMS): Characterized by the sensation of muscle discomfort/soreness during muscle contractions, which typically results from completing unaccustomed exercise 24-48 hours following the exercise bout.

Muscular Hypertrophy: The increase in the overall size of muscle fibers exhibited through an increase in diameter or cross-sectional area of muscle. With muscle hypertrophy, there is an increase in actin and myosin contractile proteins, an increase in myofibrils, sarcoplasm, and an increase in fiber connective tissue.

Muscular Strength: The ability of a muscle or muscle group to elicit maximal contractile force. It is expressed as a repetition maximum, or 1RM.

Vertical Jump (VJ): Raising one's center of gravity higher in the vertical plane using the individual's own muscles mass. It is a measure of how high an individual can elevate, or jump off the ground from a standstill position.

References

1. Barry BK, Warman GE, and Carson RG. Age-related differences in rapid muscle activation after rate of force development training of the elbow flexors. Exp Brain Res 162: 122-132, 2005.
2. Blazevich AJ, Horne S, Cannavan D, Coleman DR, and Aagaard P. Effect of contraction mode of slow-speed resistance training on the maximum rate of force development in the human quadriceps. Muscle Nerve 38: 1133-1146, 2008.
3. Burd NA, West DW, Staples AW, Atherton PJ, Baker JM, Moore DR, Holwerda AM, Parise G, Rennie MJ, Baker SK, and Phillips SM. Low-load high volume resistance exercise stimulates muscle protein synthesis more than high-load low volume resistance exercise in young men. PLoS One 5: e12033, 2010.
4. Carothers KC, Kyle F; Alvar, Brent A; Dodd, Daniel J; Johanson, Jeremy C; Kincade, Brian J; Kelly, Stephen B. Comparison Of Muscular Strength Gains Utilizing Eccentric, Standard And Concentric Resistance Training Protocols. J Strength Cond Res 24, Jan 2010.
5. Coburn J, Mahlek, MH. National Strength and Conditioning Association (NSCA) Essentials of Personal Training. 2nd ed. Human Kinetics. Champaign, IL 2012., 2012.

6. Colliander EB and Tesch PA. Effects of eccentric and concentric muscle actions in resistance training. Acta Physiol Scand 140: 31-39, 1990.
7. Crenshaw AG, Karlsson S, Styf J, Backlund T, and Friden J. Knee extension torque and intramuscular pressure of the vastus lateralis muscle during eccentric and concentric activities. Eur J Appl Physiol Occup Physiol 70: 13-19, 1995.
8. Duchateau J and Baudry S. Insights into the neural control of eccentric contractions. J Appl Physiol (1985) 116: 1418-1425, 2014.
9. Eliasson J, Elfegoun T, Nilsson J, Kohnke R, Ekblom B, and Blomstrand E. Maximal lengthening contractions increase p70 S6 kinase phosphorylation in human skeletal muscle in the absence of nutritional supply. Am J Physiol Endocrinol Metab 291: E1197-1205, 2006.
10. Enoka RM. Eccentric contractions require unique activation strategies by the nervous system. J Appl Physiol (1985) 81: 2339-2346, 1996.
11. Farthing JP and Chilibeck PD. The effect of eccentric training at different velocities on cross-education. Eur J Appl Physiol 89: 570-577, 2003.
12. Gerber JP, Marcus RL, Dibble LE, Greis PE, Burks RT, and LaStayo PC. Effects of early progressive eccentric exercise on muscle structure after anterior cruciate ligament reconstruction. J Bone Joint Surg Am 89: 559-570, 2007.
13. Gerber JP, Marcus RL, Dibble LE, Greis PE, Burks RT, and LaStayo PC. Effects of early progressive eccentric exercise on muscle size and function after anterior cruciate ligament reconstruction: a 1-year follow-up study of a randomized clinical trial. Physical therapy 89: 51-59, 2009.
14. Hather BM, Tesch PA, Buchanan P, and Dudley GA. Influence of eccentric actions on skeletal muscle adaptations to resistance training. Acta Physiol Scand 143: 177-185, 1991.
15. Higbie EJ, Cureton KJ, Warren GL, 3rd, and Prior BM. Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. J Appl Physiol (1985) 81: 2173-2181, 1996.
16. Hollander DB, Kraemer RR, Kilpatrick MW, Ramadan ZG, Reeves GV, Francois M, Hebert EP, and Tryniecki JL. Maximal eccentric and concentric strength discrepancies between young men and women for dynamic resistance exercise. J Strength Cond Res 21: 34-40, 2007.
17. Hortobagyi T, Barrier J, Beard D, Braspennincx J, Koens P, Devita P, Dempsey L, and Lambert J. Greater initial adaptations to submaximal muscle lengthening than maximal shortening. J Appl Physiol (1985) 81: 1677-1682, 1996.
18. Hortobagyi T, Devita P, Money J, and Barrier J. Effects of standard and eccentric overload strength training in young women. Med Sci Sports Exerc 33: 1206-1212, 2001.
19. Hortobagyi T, Hill JP, Houmard JA, Fraser DD, Lambert NJ, and Israel RG. Adaptive responses to muscle lengthening and shortening in humans. J Appl Physiol (1985) 80: 765-772, 1996.
20. Kerksick CM, Kreider RB, and Willoughby DS. Intramuscular adaptations to eccentric exercise and antioxidant supplementation. Amino Acids 39: 219-232, 2010.

21. LaStayo PC, Woolf JM, Lewek MD, Snyder-Mackler L, Reich T, and Lindstedt SL. Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. J Orthop Sports Phys Ther 33: 557-571, 2003.
22. Lorenz D. Eccentric Exercise Interventions for Tendinopathies. Strength and Conditioning Journal 32: 90-98, 2010.
23. Lorenz D and Reiman M. The role and implementation of eccentric training in athletic rehabilitation: tendinopathy, hamstring strains, and acl reconstruction. International journal of sports physical therapy 6: 27-44, 2011.
24. Newton R.U KWJ. Developing Explosive muscular power: Implications for a mixed methods training strategy. J Strength Cond Res 16: 21-31, 1994.
25. Nickols-Richardson SM, Miller LE, Wootten DF, Ramp WK, and Herbert WG. Concentric and eccentric isokinetic resistance training similarly increases muscular strength, fat-free soft tissue mass, and specific bone mineral measurements in young women. Osteoporos Int 18: 789-796, 2007.
26. Norrbrand L, Fluckey JD, Pozzo M, and Tesch PA. Resistance training using eccentric overload induces early adaptations in skeletal muscle size. Eur J Appl Physiol 102: 271-281, 2008.
27. Nosaka K and Newton M. Concentric or eccentric training effect on eccentric exercise-induced muscle damage. Med Sci Sports Exerc 34: 63-69, 2002.
28. Nosaka K and Newton M. Difference in the magnitude of muscle damage between maximal and submaximal eccentric loading. J Strength Cond Res 16: 202-208, 2002.
29. Roig M, O'Brien K, Kirk G, Murray R, McKinnon P, Shadgan B, and Reid WD. The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. Br J Sports Med 43: 556-568, 2009.
30. Schoenfeld BJ. Does exercise-induced muscle damage play a role in skeletal muscle hypertrophy? J Strength Cond Res 26: 1441-1453, 2012.
31. Seger JY, Arvidsson B, and Thorstensson A. Specific effects of eccentric and concentric training on muscle strength and morphology in humans. Eur J Appl Physiol Occup Physiol 79: 49-57, 1998.
32. Seger JY and Thorstensson A. Effects of eccentric versus concentric training on thigh muscle strength and EMG. Int J Sports Med 26: 45-52, 2005.
33. Shalabi A, Kristoffersen-Wilberg M, Svensson L, Aspelin P, and Movin T. Eccentric training of the gastrocnemius-soleus complex in chronic Achilles tendinopathy results in decreased tendon volume and intratendinous signal as evaluated by MRI. Am J Sports Med 32: 1286-1296, 2004.
34. Shepstone TN, Tang JE, Dallaire S, Schuenke MD, Staron RS, and Phillips SM. Short-term high- vs. low-velocity isokinetic lengthening training results in greater hypertrophy of the elbow flexors in young men. J Appl Physiol (1985) 98: 1768-1776, 2005.
35. Stupka N, Tarnopolsky MA, Yardley NJ, and Phillips SM. Cellular adaptation to repeated eccentric exercise-induced muscle damage. J Appl Physiol (1985) 91: 1669-1678, 2001.

36. Willoughby DS, Taylor M, and Taylor L. Glucocorticoid receptor and ubiquitin expression after repeated eccentric exercise. Med Sci Sports Exerc 35: 2023-2031, 2003.

CHAPTER 2

This chapter presents a review manuscript, entitled "How to Incorporate Eccentric Training Into a Resistance Training Program " that has been accepted and published in the National Strength and Conditioning Association's Strength and Conditioning Journal (SCJ) in the February 2015 issue: 37 (1): 5-17. It is authored by Jonathan Mike, Chad Kerksick, and Len Kravitz. The manuscript follows the formatting and style guidelines of the journal. The references cited are provided at the end of the manuscript.

How to Incorporate Eccentric Training Into a Resistance Training Program

Abstract

Eccentric training and eccentric muscular contractions focus on active lengthening while loaded. When compared to concentric movements, eccentric actions yield greater force levels with concomitant lower levels of neuromuscular activation. Eccentric training is mainly incorporated indirectly by strength and conditioning and fitness professionals leading to it being often underused and undervalued. Eccentric training can readily be incorporated into a training program along with the use of non-traditional exercises for all populations. This paper examines the science of eccentric training and extends this science by focusing on practical recommendations. Suggested progressions are provided depending on training background along with case study scenarios.

Key Words: Eccentric, Strength, Hypertrophy, and Rehabilitation

Introduction

Dynamic muscular contractions can be characterized by two primary actions, concentric and eccentric contractions. A concentric contraction results in muscle shortening and occurs when the force produced during a contraction exceeds the force applied to the muscle. Alternatively, an eccentric contraction occurs when the muscle is forcibly lengthened or elongated. An eccentric contraction results when the force produced inside the muscle is less than what is applied to the muscle externally (5) and results in active lengthening of the muscle fibers under some level of load. When directly compared, eccentric muscle actions are able to produce greater force in amounts estimated to be 20 – 60% greater than force levels generated during concentric activities (18). Alternatively, lower levels of neural activation have been shown in eccentric contractions when compared to concentric efforts creating a much greater force-to-neural activation ratio (40). Evidence surrounding muscle damage (loss of force production, increased soreness and myocellular protein accumulation in the serum [e.g., creatine kinase, myoglobin, etc.] as well as Z-disk streaming) are routinely reported to a greater extent when eccentric contractions are completed (34, 35). Finally, some evidence also indicates that a greater contribution from eccentric contractions may better facilitate phenotypic adaptations such as increased strength and hypertrophy (38). Eccentric training has lead to increases in hypertrophy for both concentric-only strength and eccentric-only strength. Differences do exist, however mainly from methodological design, subject history, specific load used and equipment. Taken together, all of this evidence suggests that increasing the incorporation of eccentric efforts into resistance training programs for fitness, athletic and clinical populations may improve in training outcomes. Eccentric resistance training incorporating submaximal, maximal (100% one-repetition maximum [1RM]) or supramaximal (typically 105-120% 1RM) training loads have been shown to stimulate greater increases in maximal muscle strength in traditional activities involving both concentric and eccentric actions (17, 21, 22, 33, 39), compared to conventional types of strength training (6), or even using very light loads (3). Current and recent evidence does indicate that eccentric muscle contractions are important in practically all sports that involve jumping, running, or throwing as a critical part of the stretch shortening cycle (44). Several studies showing that a relationship between improved eccentric strength and improved athletic performance does exist. For example, in fast movement (i.e. sprinting), preactivation of muscles is observed between the onset of EMG signal and the subsequent limb movement (45). In addition, preactivation of muscle immediately enhances sensitivity of muscle spindles, leading to improved regulation of reflex potentiation and stiffness throughout the subsequent eccentric phase (24). In jumping exercises, high and fast muscle activation during the eccentric phase of the takeoff improves performance (25). In addition, evidence suggests that in long-jumping, the maximal stretch in fibers of leg extensor muscles is achieved in a very short time (i.e. 15 ms) after touch down, leading to greater eccentric force enhancement than the concentrically generated force immediate prior to the kick-off (41).

While both concentric and isometric muscle contractions elicit a hypertrophy response, numerous studies have reported that eccentric actions may have the greatest effect on skeletal muscle growth (15, 21, 22, 32, 37). Importantly, some studies go one step further and indicate that the speed of the eccentric contraction may preferentially impact hypertrophic changes (11, 42). Farthing and colleagues (12) examined the effect of isokinetic eccentric and concentric training at two velocities (fast, 180 degrees) and (slow, 30 degrees) on muscle hypertrophy where they trained one arm eccentrically for 8 weeks followed by concentric training of the opposite arm for 8 weeks. Ten subjects served as non-training controls. Subjects were tested before and after training for elbow flexor muscle thickness by sonography and isokinetic strength (Biodex). The results indicated that eccentric training resulted in greater hypertrophy than concentric training. The fast eccentric training group (180 degrees) resulted in greater hypertrophy than concentric training group (180 degrees) training and concentric (30 degrees) training. However, the slow velocity (eccentric, 30 degrees) training group resulted only in greater hypertrophy than the concentric group (180 degrees) training. It's important to note that the hypertrophic superiority of eccentric training is largely attributed to a greater time under tension. It is postulated this is due to a reversal of the size principle of recruitment, resulting in fast-twitch fibers being recruited first (42). In addition, eccentric training has been shown to lead to increased hypertrophy for both concentric only strength and eccentric only strength (4, 11, 17, 20, 22). Thus from a hypertrophy perspective, it appears that movement speed during the eccentric portion of a repetition may play a role in determining how the involved muscle responds.

Eccentric training is mainly incorporated in an indirect manner by strength and conditioning as well as fitness professionals; as a result it is often underused and undervalued, and it is our contention misunderstood. Many techniques of eccentric training are available for incorporation into a training program along with the use of non-traditional exercises for able-bodied, clinical as well as athletic populations. This paper examines the scientific basis of eccentric training and extends this science by emphasizing the delivery of practical recommendations for all potential applications. In addition, suggestions for progressions are provided depending on training abilities and experience and further highlighted using case study scenarios.

Benefits of Eccentrics Training

Incorporating eccentric training and programing into a resistance training program can facilitate numerous benefits that extend well beyond simple increases in strength and hypertrophy for populations ranging from athletes desiring peak performance to clinical patients involved in physical rehabilitation. With eccentric exercise greater force output is produced during a maximal eccentric action primarily due to the ability to use higher external loads. Research focusing on the effects of overload training (100-120% 1RM) during the eccentric phase of a movement has routinely demonstrated a greater ability to develop maximal strength. Research by Doan and Colleagues (9) reported that applying a supra-maximal load (≥105% of 1RM) on the eccentric phase of the lift elicited increases in 1RM concentric strength by 5-15lbs. These abilities to increase strength have been shown to be greater when compared to concentric resistance training using lighter loads (17, 21, 22, 33, 39). In addition, a number of other adaptations have been reported in the literature in support of eccentric training and include heightened neural adaptations in response to eccentric training when compared to concentric training (22). These neural adaptations likely include spinal and cortical mechanisms (i.e. larger excitability and greater involvement of brain areas) and are areas in need of greater research (19). In addition, the energy cost of eccentric exercise is comparably low, despite the high muscle force being generated. This makes eccentrics an appealing strategy for those wishing to gain additional strength and hypertrophy due to the fact that more volume can be performed without excessive fatigue. In a fascinating display, exercise-induced hypertrophy from eccentric exercise is likely manifested by greater muscular tension under load, which has been a situation that has been mechanistically explained to represent a reversal of the size principle of motor unit recruitment, resulting in fast twitch motor units being preferentially recruited earlier in the process (42). Finally, and as a mechanistic link to reports of greater hypertrophy, eccentric exercise is also linked to more robust increases in protein synthesis (31) as well as a larger rise in IGF-1 mRNA expression (42) when compared to concentric muscle actions.

Scientific literature abounds that indicates eccentric training sessions elicit greater muscle damage when compared to concentric training as represented by a loss of force production and increases in soreness as well as increased concentrations of serum-based proteins of myofibrillar origin (34, 35). The response to damage from eccentric training is thought to be associated with a mechanical disturbance of the actomyosin bond versus ATP-dependent detachment, leading to greater stress and strain on the contractile apparatus compared to other muscle actions, increasing the susceptibility to muscle damage. (16). Other interesting findings related to muscle damage include indications that the degree of eccentric-induced muscle damage is greater in upper limb musculature when compared to lower limb (23, 36). It also appears that fusiform muscles (i.e. biceps brachii) are more susceptible to eccentric-induced damage than penniform muscles (i.e., rectus femoris) due to pennate muscles having short fascicles that attach obliquely to a central tendon running the length of the muscle (23). Lastly, evidence also indicates that a fiber-type specific response to muscle damage may occur whereby type II muscle fibers appear to be more vulnerable to damage during eccentric exercise than type I muscle fibers (30, 43). Whether or not these intramuscular factors will eventually result in altered eccentric prescriptions primarily in clinical populations to avoid (or promote) damage and its ensuing repair and remodeling phase's remains to be seen, but the scientific foundation is present for such considerations to be entertained.

As mentioned previously, incorporating eccentric training not only benefits healthy adults and athletic populations, but these benefits also extend to a number of clinical populations. For example, the aging process results in a progressive and continual reduction in muscle strength. For this reason alone, incorporation of eccentric training could be considered in an elderly population for its known ability to improve muscle strength and power while also reducing their risk for falls and potential fracture risk (26, 27). With respect to increases in power, eccentric exercise training serves an important part in all aspects of sports and is critical during the strength shortening cycle (44), and has been shown to be an effective modality in increasing (explosive) muscle strength, muscle cross-sectional area, leading to increased sarcomere length. Recent evidence suggests eccentric and over-speed training modalities are effective in improving components of muscular power and eccentric training induces specific training adaptations relating to muscular force. It was found that eccentric training with over-speed stimuli was more effective than traditional resistance training in increasing peak power in the countermovement jump (8).

Other clinical populations can benefit from incorporating eccentric training, particularly if the patient exhibits a low level of strength and is just beginning a resistance training or rehabilitation program. For example, research involving stroke and COPD patients has demonstrated a significant preservation of eccentric strength when compared to age-matched healthy controls (10, 29). Additionally, increases in collagen synthesis and improvements in overall bodily function (13) regularly occur as part of a comprehensive rehabilitation program.

Physical rehabilitation populations can also derive benefits from eccentric training, starting first with the known cross-education effect or the transfer of strength gains unilaterally from one limb/side to the other (11). Protocols using cross-education have been shown to successfully improve quadriceps strength in the limbs of healthy, uninjured participants, although the exact mechanism are still not yet fully explained. Recent evidence examined the effect of eccentric exercise on quadriceps strength and activation gains in the unexercised limb. Eighteen healthy individuals were randomly assigned to an eccentric training group or a control group. Quadriceps strength and activation were measured pre, mid, and post intervention. Eccentric training participants exercised their dominant limb with a dynamometer in eccentric mode at 60 degrees /s, 3 times per week for 8 weeks and found greater eccentric strength in the unexercised limbs in eccentric training participants between trials. It was concluded that exercising with eccentric actions resulted in mode-specific and velocity-specific improvements in quadriceps strength in the unexercised limb, suggesting that strength gains may have occurred because of enhanced neural activity (28).

Incorporating Eccentrics Into Your Program

A variety of eccentric training techniques are available along with the use of a number of non-traditional exercises for able-bodied, clinical as well as athletic populations. While several eccentric techniques exist that strength and conditioning and fitness professionals can employ, four categories of eccentric techniques are most commonly used. These four techniques are highlighted in the following section.

2/1 Technique: The 2/1 technique for emphasizing the eccentric component involves lifting the weight through its concentric range of motion with two limbs, while moving the weight back through the eccentric phase with one limb. It should be emphasized that the load should be heavy enough to pull through the concentric phase as quick as possible, but heavy enough to challenge the individual throughout the eccentric portion. Specifically, the load during the eccentric phase should be twice as high as during the concentric phase, and an approximate load of 70% of bilateral concentric 1RM is considered to be a general starting point. Sets of three to five reps per limb are performed (six to ten total reps per set), with a rest interval of 60 seconds. Tables 1 and 2 provide examples of several exercises that can be modified to accentuate the eccentric phase using any of the techniques highlighted throughout this manuscript. Finally, past experiences and personal observation of utilizing this technique indicate that a wide variety of populations can benefit from its use.

<<< Insert Table 1 and Table 2 about here >>>

Two-Movements Technique**:** The two-movements technique is slightly more technical as compared to the 2/1 eccentric technique. With the two-movement technique, it is recommended the concentric portion should be a compound (multi-joint) exercise coupled with an isolation exercise for the eccentric portion of the lift. It is our contention through personal experience and coaching that this technique should be practiced among more highly trained individuals. The volume and load parameters should consist of 90 – 110% of your maximal load while incorporating 4-5 sets of 5 repetitions with an eccentric duration of 5 seconds. Rest periods should be one to two minutes in between sets. Sample exercises using this technique (i.e.; power clean/reverse curl, close-grip bench/tricep extension, etc.) as well as basic prescription recommendations are provided in table 2.

Slow/Superslow: This technique is relatively simple. The lifter executes an exaggerated, slow speed eccentric phase while concentrically lifting the bar explosively. This is perhaps one of the more common eccentrically emphasized techniques in comparison to the other techniques, and as a result it has been used to a greater extent. Again, we have attempted to provide details in table 2 with regards to this technique. It should be emphasized that the eccentric duration varies depending on the load used. For example, a lower % 1RM yields a longer eccentric duration (i.e. 60% 10-12 seconds), while a heavier load (i.e. 85%) would likely yield approximate 4-second eccentric contraction duration. A load ranging from 60-85% 1RM is commonly employed using eccentric contraction durations ranging from 2 – 15 seconds, depending load assignment, type of movement, size of muscle group, etc. A rest period of 60 seconds is commonly used that could be further modified depending on other details found within the overall exercise prescription.

Negative (Supramax): This type of training primarily refers to the eccentric action, and is mainly used as an eccentrically emphasized training technique. Although an effective technique, one drawback is that it requires at least one spotter and depending on the exercise, load and number of eccentric repetitions to be completed, two or three spotters may be needed. For example, when performing a bench press, one to two spotters are recommended. There should be no actual concentric lift with this type of technique, which commonly results in the spotter concentrically lifting the bar to the starting position after the lifter performs the eccentric rep. Therefore, the lifter should focus their efforts on eccentric control throughout the supra-maximal technique. As indicated in table 2, sets of one repetition should be used with 110-130% of concentric 1RM. However, the time of the eccentric action is load dependent with 110 and 130% of your maximum. For example, an 8-10 second eccentric contraction can be expected if the load is 110-120% concentric 1RM. Further, the lifter may increase the load percentage (125 – 130% concentric 1RM) which will decrease the overall duration of the eccentric phase to somewhere around four to five seconds in duration. When performing this specific technique, it is recommended three to ten sets of singular repetitions be completed at a load of 110 – 120% 1RM. We recommend starting conservatively with this technique as it places a large demand on the nervous system and therefore can elicit rapid periods of overreaching and potentially overtraining. As a result, the individual should take a longer rest interval when using this technique and closely evaluate recovery, soreness, etc. before completing a subsequent workout using this technique. Provided that a muscle is not fully fatigued during concentric training (46), the use of heavy negatives (supramax) may elicit greater motor unit fatigue and thus provide an additional hypertrophic stimulus. The greatest improvements using supra-maximal eccentrics (110–120% 1RM) have been reported by Brandenburg and Docherty (1) who reported an increase in elbow extensor strength of 24% compared with 15% using standard resistance training after 10 weeks of training 2–3 times per week. Similar results were also reported by Doan and colleagues (9) who applied a supra-maximal load (≥105% of 1RM) on the eccentric phase of the lift and elicited increases in 1RM concentric strength.

Scenarios

The following section is included in the hopes it will help facilitate a broader understanding of how eccentric techniques can be employed and hopefully stimulate additional thought by the reader to further apply the different eccentric techniques. Both scenarios are intended to build upon the information outlined in tables 1 and 2.

Scenario 1:

A 240lb football player has a severe hamstring strain. In order to facilitate recovery and strength, it is recommended the individual incorporate eccentric training into his program. His goals are to restore range of motion and strength and to use specific hamstring exercises to assist in this process. Once the initial inflammation phase has been resolved (i.e. 1-4 weeks), he can begin to primarily use open kinetic chain and non-weight bearing exercises. Once the athlete has tolerated the non-weight bearing exercises, Comfort et al (7) have suggested to implement low-velocity eccentric activities such as stiff leg dead lifts, eccentric hamstring lowering exercises, and split squats. Based on the recommendations from Comfort et al (7), the next phase involves higher velocity eccentric exercises that include plyometric and sport specific activities designed to increase hamstring torque and lower extremity power. Examples include squat jumps, split jumps, bounding, and depth jumps. Finally, sports related progressions should complete the program. Comfort et al (7) suggest progressing from unidirectional linear movements to bidirectional and then multidirectional movements. These examples may include progressions from two-leg jumps, single leg hops, single leg bounding, backward skips, lateral hops, lateral bounding, and zigzag hops and bounding. Further, evidence from Brughelli and Cronin (2) propose that incorporating eccentric exercise for reducing the frequency of hamstring strains should include the following: high force, maximal muscle elongation, high velocity, multi-joint movements, closed-chain exercises, unilateral exercises. These include eccentric lunge drops, eccentric single and double leg deadlifts, and even a split stance "good morning" exercise with the load positioned in front compared to a posterior load on the back. It should be noted that we have provided similar eccentric emphasized exercises for the lower body (table 1) that can also be used in this scenario example for the specific eccentric contraction duration with the recommended set and rep scheme.

<<<Insert Figures 1 and 2 Here>>>

<<<Insert Figures 3, 4 and 5 Here>>>

Scenario 2

An advanced 28-year old female lifter with 10 years training experience would like to incorporate some eccentric emphasized training into her training program in order to assist in further development of strength and hypertrophy. She has competed in strength sports throughout high school and college and continues to compete recreationally for the past six years while recently completing three bodybuilding competitions in the past two years. With this scenario, multiple eccentric-focused resistance-training techniques can be employed utilizing exercises available in most commercial gyms:

<<<Insert Figures 6, 7 and 8 Here>>

>>>Insert Figures 9, 10, 11, 12 and 13 Here>>>

2/1 Technique:

The 2/1 technique is an ideal eccentric technique for this type of scenario. For example, using bilateral machines (i.e.; leg press or chest press) while raising the load with both limbs and lowering with only one limb will limit fatigue and allow the lifter to complete more eccentric contractions. Both of these examples can also be completed with dumbbells, but care and caution need to be paid towards muscular failure with weights overhead. Additionally, eccentric one-arm pushups can be completed using the 2/1technique by pressing up with both arms and lowering with one arm.

Cluster Sets With Eccentric Emphasis:

Cluster sets involve of a series of repetitions interspersed by a very short (i.e.; 5-30 seconds) rest interval (14). A well-known modern-day example of this training style is a “rest–pause” set. A partner or spotter helps raise the weight to the starting position. From here, the lifter begins each series of repetitions with an eccentric contraction and completes the set (after concentric failure or as the last rep performed) with an eccentric contraction to a safe stopping point. With the technique, the lifter can accumulate additional eccentric contractions over the course of a multi-series cluster set.

Forced Eccentrics (Surpamaximal Technique):

These are primarily completed in a fatigued state with lighter loads. For example, as one reaches concentric failure at the end of a drop set, the spotter helps lift the weight and provides an additional load during the eccentric portion so that the eccentric tempo is relatively normal or even slower. In current bodybuilding culture, this is often referred to as “isotension,” where isometric contractions are performed with additional tension provided by a spotter.

Conclusions

Eccentric contractions are a distinct phase of nearly every muscular contraction that is represented by a combination of several unique factors, which ultimately impact how the involved musculature responds. A number of eccentric training strategies exist that can allow for a wide variety of applications across nearly all populations. While eccentrically dominated movements may not be needed in all situations, it is our contention that nearly all populations can indeed derive benefit. Towards this aim, the approach taken throughout this article was to highlight a number of different eccentric strategies along with examples and potential prescriptive scenarios upon implementation to encourage the reader to incorporate and explore other means in which eccentric can be incorporated into their athletes or client’s programs. From this article, we hope to better highlight many ways how eccentrics can be incorporated into the training and therapy programs of active, athletic and clinical populations.

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References

1. Brandenburg JP and Docherty D. The effects of accentuated eccentric loading on strength, muscle hypertrophy, and neural adaptations in trained individuals. J Strength Cond Res 16: 25-32, 2002.
2. Brughelli M CJ. Preventing hamstring injuries in sport. Strength Cond J: 55-64, 2008.
3. Burd NA, West DW, Staples AW, Atherton PJ, Baker JM, Moore DR, Holwerda AM, Parise G, Rennie MJ, Baker SK, and Phillips SM. Low-load high volume resistance exercise stimulates muscle protein synthesis more than high-load low volume resistance exercise in young men. PLoS One 5: e12033, 2010.
4. Carothers KC, Kyle F; Alvar, Brent A; Dodd, Daniel J; Johanson, Jeremy C; Kincade, Brian J; Kelly, Stephen B. Comparison Of Muscular Strength Gains Utilizing Eccentric, Standard And Concentric Resistance Training Protocols. J Strength Cond Res 24, Jan 2010.
5. Coburn J, Mahlek, MH. National Strength and Conditioning Association (NSCA) Essentials of Personal Training. 2nd ed. Human Kinetics. Champaign, IL 2012., 2012.
6. Colliander EB and Tesch PA. Effects of eccentric and concentric muscle actions in resistance training. Acta Physiol Scand 140: 31-39, 1990.
7. Comfort P GC, Matthews M. . Training considerations after hamstring injury in athletes. Strength Cond J 31: 68-74, 2009; 31: 68-74.
8. Cook CJ, Beaven CM, and Kilduff LP. Three weeks of eccentric training combined with overspeed exercises enhances power and running speed performance gains in trained athletes. J Strength Cond Res 27: 1280-1286, 2013.
9. Doan BK, Newton RU, Marsit JL, Triplett-McBride NT, Koziris LP, Fry AC, and Kraemer WJ. Effects of increased eccentric loading on bench press 1RM. J Strength Cond Res 16: 9-13, 2002.
10. Eng JJ, Lomaglio MJ, and Macintyre DL. Muscle torque preservation and physical activity in individuals with stroke. Med Sci Sports Exerc 41: 1353-1360, 2009.
11. Farthing JP and Chilibeck PD. The effect of eccentric training at different velocities on cross-education. Eur J Appl Physiol 89: 570-577, 2003.
12. Farthing JP and Chilibeck PD. The effects of eccentric and concentric training at different velocities on muscle hypertrophy. Eur J Appl Physiol 89: 578-586, 2003.
13. Gerber JP, Marcus RL, Dibble LE, Greis PE, Burks RT, and LaStayo PC. Effects of early progressive eccentric exercise on muscle size and function after anterior cruciate ligament reconstruction: a 1-year follow-up study of a randomized clinical trial. Physical therapy 89: 51-59, 2009.
14. Haff GG, et al. Cluster training: A novel method for introducing training program variation. . Strength Cond J: Strength Cond. J., 2008.

15. Hather BM, Tesch PA, Buchanan P, and Dudley GA. Influence of eccentric actions on skeletal muscle adaptations to resistance training. Acta Physiol Scand 143: 177-185, 1991.
16. Herzog W. Mechanisms of enhanced force production in lengthening (eccentric) muscle contractions. J Appl Physiol (1985), 2013.
17. Higbie EJ, Cureton KJ, Warren GL, 3rd, and Prior BM. Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. J Appl Physiol (1985) 81: 2173-2181, 1996.
18. Hollander DB, Kraemer RR, Kilpatrick MW, Ramadan ZG, Reeves GV, Francois M, Hebert EP, and Tryniecki JL. Maximal eccentric and concentric strength discrepancies between young men and women for dynamic resistance exercise. J Strength Cond Res 21: 34-40, 2007.
19. Hoppeler H and Herzog W. Eccentric exercise: many questions unanswered. J Appl Physiol (1985) 116: 1405-1406, 2014.
20. Hortobagyi T, Barrier J, Beard D, Braspennincx J, Koens P, Devita P, Dempsey L, and Lambert J. Greater initial adaptations to submaximal muscle lengthening than maximal shortening. J Appl Physiol (1985) 81: 1677-1682, 1996.
21. Hortobagyi T, Devita P, Money J, and Barrier J. Effects of standard and eccentric overload strength training in young women. Med Sci Sports Exerc 33: 1206-1212, 2001.
22. Hortobagyi T, Hill JP, Houmard JA, Fraser DD, Lambert NJ, and Israel RG. Adaptive responses to muscle lengthening and shortening in humans. J Appl Physiol (1985) 80: 765-772, 1996.
23. Jamurtas AZ, Theocharis V, Tofas T, Tsiokanos A, Yfanti C, Paschalis V, Koutedakis Y, and Nosaka K. Comparison between leg and arm eccentric exercises of the same relative intensity on indices of muscle damage. Eur J Appl Physiol 95: 179-185, 2005.
24. Kyrolainen H and Komi PV. Differences in mechanical efficiency between power- and endurance-trained athletes while jumping. Eur J Appl Physiol Occup Physiol 70: 36-44, 1995.
25. Kyrolainen H and Komi PV. The function of neuromuscular system in maximal stretch-shortening cycle exercises: Comparison between power- and endurance-trained athletes. J Electromyogr Kinesiol 5: 15-25, 1995.
26. LaStayo PC, Ewy GA, Pierotti DD, Johns RK, and Lindstedt S. The positive effects of negative work: increased muscle strength and decreased fall risk in a frail elderly population. J Gerontol A Biol Sci Med Sci 58: M419-424, 2003.
27. LaStayo PC, Woolf JM, Lewek MD, Snyder-Mackler L, Reich T, and Lindstedt SL. Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. J Orthop Sports Phys Ther 33: 557-571, 2003.
28. Lepley LK and Palmieri-Smith RM. Cross-Education Strength and Activation After Eccentric Exercise. J Athl Train, 2014.
29. Mathur S, MacIntyre DL, Forster BB, Road JD, Levy RD, and Reid WD. Preservation of eccentric torque of the knee extensors and flexors in patients with COPD. J Cardiopulm Rehabil Prev 27: 411-416, 2007.

30. McHugh MP, Tyler TF, Greenberg SC, and Gleim GW. Differences in activation patterns between eccentric and concentric quadriceps contractions. J Sports Sci 20: 83-91, 2002.
31. Moore DR, Phillips SM, Babraj JA, Smith K, and Rennie MJ. Myofibrillar and collagen protein synthesis in human skeletal muscle in young men after maximal shortening and lengthening contractions. Am J Physiol Endocrinol Metab 288: E1153-1159, 2005.
32. Nickols-Richardson SM, Miller LE, Wootten DF, Ramp WK, and Herbert WG. Concentric and eccentric isokinetic resistance training similarly increases muscular strength, fat-free soft tissue mass, and specific bone mineral measurements in young women. Osteoporos Int 18: 789-796, 2007.
33. Norrbrand L FJ, Pozzo M, Tesch PA. Eccentric overload appears necessary to optimize skeletal muscle adaptations to chronic resistance exercise. Eur J Appl Physiol 102: 271-281, 2008.
34. Nosaka K and Newton M. Concentric or eccentric training effect on eccentric exercise-induced muscle damage. Med Sci Sports Exerc 34: 63-69, 2002.
35. Nosaka K and Newton M. Difference in the magnitude of muscle damage between maximal and submaximal eccentric loading. J Strength Cond Res 16: 202-208, 2002.
36. Paschalis V, Nikolaidis MG, Theodorou AA, Giakas G, Jamurtas AZ, and Koutedakis Y. Eccentric exercise affects the upper limbs more than the lower limbs in position sense and reaction angle. J Sports Sci 28: 33-43, 2010.
37. Roig M, O'Brien K, Kirk G, Murray R, McKinnon P, Shadgan B, and Reid WD. The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. Br J Sports Med 43: 556-568, 2009.
38. Schoenfeld BJ. Does exercise-induced muscle damage play a role in skeletal muscle hypertrophy? J Strength Cond Res 26: 1441-1453, 2012.
39. Seger JY, Arvidsson B, and Thorstensson A. Specific effects of eccentric and concentric training on muscle strength and morphology in humans. Eur J Appl Physiol Occup Physiol 79: 49-57, 1998.
40. Seger JY and Thorstensson A. Effects of eccentric versus concentric training on thigh muscle strength and EMG. Int J Sports Med 26: 45-52, 2005.
41. Seyfarth A, Blickhan R, and Van Leeuwen JL. Optimum take-off techniques and muscle design for long jump. J Exp Biol 203: 741-750, 2000.
42. Shepstone TN, Tang JE, Dallaire S, Schuenke MD, Staron RS, and Phillips SM. Short-term high- vs. low-velocity isokinetic lengthening training results in greater hypertrophy of the elbow flexors in young men. Journal of applied physiology (Bethesda, Md : 1985) 98: 1768-1776, 2005.
43. Vijayan K, Thompson JL, Norenberg KM, Fitts RH, and Riley DA. Fiber-type susceptibility to eccentric contraction-induced damage of hindlimb-unloaded rat AL muscles. J Appl Physiol (1985) 90: 770-776, 2001.
44. Vogt M and Hoppeler HH. Eccentric exercise: mechanisms and effects when used as training regime or training adjunct. J Appl Physiol (1985) 116: 1446-1454, 2014.

45. Vos EJ, Harlaar J, and van Ingen Schenau GJ. Electromechanical delay during knee extensor contractions. Med Sci Sports Exerc 23: 1187-1193, 1991.
46. Willardson JM. The application of training to failure in periodized multiple-set resistance exercise programs. J Strength Cond Res 21: 628-631, 2007.

FIGURE LEGENDS

FIGURE 1: Starting position of single leg stiff-legged deadlift (SLDL). Athlete should strive to stay arched as much as possible while driving the back leg up with hip extended, and use a slight knee bend in the front leg. There should be little hip rotation.

FIGURE 2: Finish position of single-leg stiff-legged deadlift (SLDL).

FIGURE 3: Starting position of glute/ham Raise: Athletes should place their feet against the footplate in between the rollers as they lie facedown. The knees should be just behind the pad. Incorporating the eccentric emphasized technique(s), the athletes should start from the top of the movement. Keep your body straight and stay braced with the core. Slowly move down focusing on the eccentric portion while keeping upper body straight, and continue until you are fully extended.

FIGURE 4: Mid-position of glute/ham Raise

FIGURE 5: Finish position of glute/ham Raise

FIGURE 6: Starting position of eccentric pull-up using a supinated grip. The athletes can also use various grip positions such as double overhand, neutral, narrow, or wide.

FIGURE 7: Mid-position of eccentric pull-up

FIGURE 8: Finish position of eccentric pull-up

FIGURE 9: Starting position of barbell hip thrust. The bar should be positioned in the crease of the hip with the hands holding the bar into position throughout the movement so the bar does not move forwards or backwards.

FIGURE 10: Top position of barbell hip thrust. At the top, the hips should be fully extended, with the shins vertical. The athletes should complete the lift by contracting the glutes hard and pushing the hips forward. The low back should not be overextended. At the top of the movement your torso should be parallel to the ground.

FIGURE 11: Top position with leg elevated of barbell hip thrust. Athlete should strive to keep the lifted leg perpendicular to ground through movement for balance and added core stability.

FIGURE 12: Middle position with leg elevated of barbell hip thrust (downward motion).

FIGURE 13: Finish position of barbell hip thrust.

FIGURE 14: Picture of Jonathan Mike

FIGURE 15: Head and shoulder picture of Chad Kerksick

FIGURE 16: Head and shoulder picture of Len Kravitz

Table 1: Eccentric Emphasized Exercises- Upper and Lower Body

Exercise	Eccentric Duration	Emphasis	Sets and Reps	Suggested Eccentric Technique
TRX Row	3-5 seconds	Upper Body	3-5 sets x 6-8 reps	2/1; SuperSlow
Pull-ups	3-5 seconds	Upper Body. Can focus on Eccentric-Only or Perform Concentric with Eccentric Emphasis	3-5 sets x 8-10 reps with Concentric; 3-5 sets x 6-8 reps with Eccentric-Only	Superslow *Can use heavier loading and decrease eccentric duration (i.e. 85%1RM for 4-seconds *Bodyweight and Strength dependent
Glute-Ham Raise	3-5 seconds	Lower Body. Focus on Eccentric-Only or Perform normal Concentric reps with Eccentric Emphasis with prescribed duration	3-5 sets x 8-10 reps with Concentric; 3-5 sets x 10-12 reps with Eccentric-Only	Slow *Bodyweight and Strength dependent. Can also use plates or bands
Manually Glute-Ham Raise	3-5 seconds	Lower Body. Can focus on Eccentric-Only *Requires a partner	3-5 sets x 10-12 reps with Eccentric-Only	Supra-max; Slow *Supra-max was chosen for this exercise due to the overall difficulty † Bodyweight and Strength dependent. Can also use plates or bands

Single Leg Romanian Deadlift or Good Mornings. (barbell or dumbbell)	3-5 seconds	Lower Body. Can focus on Eccentric-Only or Perform normal Concentric reps with Eccentric Emphasis with prescribed duration	3-5 sets x 8-10 reps with Concentric; 3-5 sets x 10-12 reps with Eccentric-Only	Two- Movements Technique
Glute-Bridge and Hip Thrust (body weight, plates or barbell) *Can also perform single leg movements	3-5 seconds	Lower Body. Can focus on Eccentric-Only or Perform normal Concentric reps with Eccentric Emphasis with prescribed duration.	3-5 sets x 8-10 reps with Concentric; 3-5 sets x 6-8 reps with Eccentric-Only	Supra-max; Slow *The use of plates, or loaded barbell can be used for Supra-max in addition to slow techniques
Half-Kneel-Bottom-Up Press-Eccentric-Only	3-5 seconds	Upper Body. Mainly focused on eccentric –only while also incorporating half-kneeling position and additional core and hip stability. *Can be used for concentric portion and eccentrically emphasized or Eccentric-only	3-5 sets x 6-8 reps	2/1 Technique; Slow; Supra-max *Can be used as a mix of all

Table 2: Eccentric Training Techniques

Technique	How to Perform	Eccentric Duration	Sets and Reps	Example Exercises
2/1 Technique	• Lift the weight concentrically using two limbs (both arms for upper body, both legs for lower body) • Return weight eccentrically with one limb.	5 seconds	• 70-80% 1RM of your selected exercises • 60s rest	• Rowing, various bicep and triceps exercises that can be done using the triceps rope, dumbbells, free weight and machines • See table 1
Two-Movements Technique	Use a compound movement (i.e. bench press; power clean) and the eccentric portion of an isolation movement.	5 seconds	4-5 sets x5 90-110% 1RM of the weight typically used for your selected exercises. For example, use 90-110% 1RM of your reverse curl or tricep extension. 60s rest	Power clean/reverse curl, Close-grip bench/tricep extension, DB Bench/Flies, DB Squat/single leg DB Squat)
Slow/SuperSlow	Execute a super slow eccentric phase while concentrically lifting the bar explosively.	Varies depending on the load. Lower % 1RM yields a longer eccentric duration (i.e. 60% 10-12 seconds	60-85% of your max. 60s rest	Various single arm and single leg exercises (i.e. tricep pushdowns, dumbbell split squat
Negative (Supra-max)	Performing the eccentric-only portion of an exercise. *Requires a spotter	The eccentric action is load dependent	Set of 1 rep. 110 and 130% of your maximum 8-10 seconds if the load is 110-120% 4-6 seconds, 6-8seconds if the load is 120-130%	Close Grip Bench, bicep curls

Chapter 3

This chapter presents a complete manuscript that describes the study in traditional journal article form including an abstract, introduction, methods, results, discussion, practical application, acknowledgments, and references. The manuscript, entitled "The Effect of Eccentric Contraction Duration on Muscle Strength, Power Production, Vertical Jump, and Soreness" will be submitted to the Journal of Strength and Conditioning Research. It is authored by Jonathan Mike, Nathan Cole, Chris Herrera, Trisha McLain, Len Kravitz, and Chad Kerksick. The manuscript follows the formatting and style guidelines of the journal. The references cited are provided at the end of the manuscript.

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The Effects of Eccentric Contraction Duration on Muscle Strength,

Power Production, Vertical Jump and Soreness

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ABSTRACT

Prior research has investigated the effects of either eccentric-only training or comparing eccentric and concentric exercise on changes related to strength and power expression, but no research to date has investigated the impact of altering the duration of either the concentric or eccentric component on these parameters. Therefore, the purpose of this study was to assess the duration of eccentric (i.e. 2-second, 4-second vs. 6-second) muscle contractions and their effect on muscle strength, power production, vertical jump and soreness using a plate-loaded barbell Smith squat exercise. Thirty college-aged males (23 ± 3.5 years, 178 ± 6.8 cm, 82 ± 12 kg and 11.6 ± 5.1 % fat) with 3.0 ± 1.0 years of resistance training experience and training frequency of 4.3 ± 0.9 days per week were randomized and assigned to one of three eccentric training groups that incorporated different patterns of contraction. For every repetition, all three groups utilized two-second concentric contractions and paused for one second between the concentric and eccentric phases. The control group (2S) utilized two-second-eccentric contractions while the 4S group performed four-second eccentric contractions and the 6S performed six-second eccentric contractions. All repetitions were completed using the barbell Smith squat exercise. All participants completed a four-week training protocol that required them to complete two workouts per week using their prescribed contraction routine for 4 sets of 6 repetitions at an intensity of 80 – 85% 1RM. Two-way mixed factorial ANOVA were used to determine changes among groups. A p-value of 0.05 was used for all statistical determinations. At baseline, no between-group differences ($p > 0.05$) were found for any anthropometric, 1RM or dietary data with the exception of absolute protein intake ($p = 0.03$). For all performance data, significant group x time interaction effects were found for average power production across all three sets of a squat jump protocol ($p = 0.04$) while vertical jump did not reach significance but there was a trend towards a difference (GxT, $p = 0.07$). No other significant ($p > 0.05$) group x time interaction effects were found for the performance variables. All groups showed significant main effects for time in 1RM ($p < 0.001$), vertical jump ($p = 0.004$), peak power ($p < 0.001$) and average power ($p < 0.001$). Peak velocity data indicated that the 6S group experienced a significant reduction in peak velocity during the squat jump protocol as a result of the 4-week training program ($p = 0.03$). Soreness data revealed significant increases across time in all groups at both week 0 and week 4. Paired sample t-tests revealed greater differences in soreness values across time in the 2S group. The results provide further evidence that resistance training with eccentrically dominated movement patterns can be an effective method to acutely increase maximal strength and power expression in trained college age men. Furthermore, longer eccentric contractions may negatively impact explosive movements such as the vertical jump while shorter eccentric contractions may instigate greater amounts of soreness. These are important considerations for the strength and conditioning professional to more fully understand that expressions of strength and power through eccentric training and varying durations of eccentric activity can have a significant impact for populations ranging from athletes desiring peak performance.

Key Words: eccentric, duration, strength, force production, power, neural

INTRODUCTION

Dynamic muscular contractions can be characterized by two primary actions, concentric and eccentric contractions. A concentric contraction results in muscle shortening and occurs when the force produced during a contraction exceeds the force applied to the muscle. Alternatively, an eccentric contraction occurs when the muscle is forcibly lengthened or elongated. An eccentric contraction results when the force produced inside the muscle is less than what is applied to the muscle externally (9) and results in active lengthening of the muscle fibers under some level of load. When directly compared, eccentric muscle actions are able to produce greater force, an amount estimated to be 20 – 60% higher than concentric strength levels (23), and in the same respect lower levels of neural activation have been shown in eccentric contractions when compared to concentric efforts (41). Evidence surrounding muscle damage (loss of force production, increased soreness and myocellular protein accumulation in the serum as well as Z-disk streaming) is routinely reported to a greater extent when eccentric contractions are completed (35, 36). Finally, some evidence also indicates that a greater contribution from eccentric contractions may better facilitate phenotypic adaptations such as increased strength and hypertrophy (38). Taken together, all of this evidence suggests that increasing the incorporation of eccentric efforts into resistance training programs for fitness, athletic and clinical populations may improve in training outcomes.

Researchers routinely report that lower levels of neural activation (41) occur during eccentric contractions when compared to concentric efforts, providing some level of indication that typical loading patterns used as part of resistance exercise prescriptions might be dependent upon the muscle actions involved. Eccentric resistance training incorporating submaximal, maximal (100% 1RM) or supramaximal (> 100% 1RM) training loads have been shown to stimulate greater increases in maximal muscle strength (22, 24, 25, 34, 40) compared to conventional types of strength training (10), or using very light loads of resistance training (5). In addition and while both concentric and isometric muscle contractions elicit a hypertrophy response, numerous studies have reported that eccentric actions may have the greatest effect on skeletal muscle growth (20, 24, 25, 32, 37). Importantly, some studies go one step further and indicate that the speed of the eccentric contraction may have a predominant influence over the resulting hypertrophy (19, 44). Thus from a hypertrophy perspective, it appears that movement speed during the eccentric portion of a repetition may play a significant role in determining how the involved muscle responds.

When looking closely at the impact of contraction speed, most work has centered upon the entire eccentric-concentric contraction of varying speeds with little to no work focused upon the specific impact of altering the contraction speed and/or duration of only part of the contraction cycle (concentric only or eccentric only). In this respect, resistance training regimens that involve a rapid production of force can impact changes in the rate of force development (RFD) and resulting power production (31). Increases in power production have been shown to result from slower-speed training along with increases in agonist muscle activation (2). For example, Blazevich (2008) examined the effects of slow-speed resistance training involving concentric versus eccentric on contractile rate of force development (RFD) involving isometric knee extension. They found that subjects with a lower ability to rapidly attain their maximum force before training improved RFD with slow-speed resistance exercise (3). Furthermore, a meta-analysis by Roig (37) compared the effectiveness of exercise modalities at eliciting muscular adaptations and he reported that high-intensity eccentric training was associated with greater muscular adaptations than concentric training, but the impact of changing the duration of the eccentric contractions remains undetermined.

In addition to force production dynamics and neural contributions, available literature indicates that acute bouts of eccentric contractions elicit greater muscle damage compared to concentric training (35, 36), which is commonly assessed by evaluating changes in force production, self-reported soreness and serum levels of creatine kinase (28, 47, 51). Moreover, a recent review suggests that some level of damage may be needed to facilitate other adaptations such as muscle hypertrophy (38), which supports the need to better understand how manipulations of eccentric contractions may impact resulting physiological adaptations.

Finally, many studies have employed isokinetic dynamometers to execute the isokinetic eccentric actions. While valuable for their ability to control the contraction speed, laboratory-based isokinetic measurements are expensive, lack portability and typically only employ single-joint muscle actions (e.g., knee extension or elbow flexion) that are difficult to replicate to real-world resistance training situations. Therefore, the purpose of this study is to examine the impact of four weeks of eccentric training at a load equivalent to 80% 1RM using different durations of eccentric contractions using a commercially available Smith machine squat rack on charges related to strength, power production, vertical jump and soreness.

METHODS

Experimental Approach to the Problem

Using a randomized, repeated measures design, with parallel independent groups this study examined the impact of eccentric contraction duration as part of an eccentric training program for changes in strength, power production, vertical jump and soreness parameters. After assessing inclusion criteria and signing IRB-approved consent forms, subjects initially completed a familiarization session where they practiced vertical jump testing, determined their 1RM and performed the power testing protocol. Upon completion of the familiarization session, all study participants completed a four-day dietary record and had their body composition determined using skinfolds for demographic purposes before beginning the study protocol. Thirty healthy, college-aged men (23 ± 3.5 years, 178 ± 6.8 cm, 82 ± 12 kg, 12 ± 5.1 % fat) with 3.0 ± 1.0 years of resistance training experience and an average weekly training frequency of 4.3 ± 0.9 days per week. In a randomized fashion, participants were assigned to one of three exercise groups that required them to complete all prescribed repetitions with different durations of eccentric contractions using the barbell Smith squat exercise. The first group utilized a traditional concentric-eccentric training duration consisting of two-second concentric contractions, a one-second pause, and a two-second-eccentric contraction (39). This group is referred to as the 2S group (n= 10) and operated as a control group in our study design. A second group (4S, n= 9) performed four- second eccentric contractions (two-second concentric contraction, one-second pause and four-second eccentric contraction) while a third group (6S, n= 11)) completed six-second eccentric contractions (two-second concentric contraction, one-second pause and six-second eccentric contraction). All exercise training sessions occurred at approximately the same time each day. Subjects completed an eccentric exercise protocol consisting of four sets of six eccentric contractions of the barbell Smith squat exercise using 80 – 85% 1RM. Experienced strength and conditioning professionals supervised every repetition and provided verbal and auditory cues using a metronome to instruct each participant on their required cadence for each repetition. No rest was provided between repetitions and three minutes of rest was used between sets. Each participant completed four weeks of training at a frequency of two days per week with each workout being separated by 72 hours. Thus, each participant completed a total of eight workouts. To assess both the acute and prolonged impact of training with different durations of eccentric contractions, measurements were taken to assess strength, power, and vertical jump before the first workout and after the final workout. In conjunction with previous literature that has reported on increases in muscle soreness in response to eccentric contractions (8, 28), each subject provided their level of soreness using a visual analog scale before, immediately post training, as well as 24, 48, and 72 hours after completion of their first and final workouts. To assess changes in power production, each subject had their vertical jump determined before (pre) completion of their first workout and after the final workout. All testing sessions were standardized for all subjects allowing for 72 hours of recovery between the final workout and post-testing measurements.

Subjects

All data collection was conducted at the Exercise Physiology Laboratories at the University of New Mexico (Albuquerque) at an altitude of 1600 m (5,400 ft.) and an approximate barometric pressure of 630 mmHg. Subjects for this investigation included thirty resistance-trained, college age males (23 ± 3.5 years, 178 ± 6.8 cm, 82 ± 12 kg and 11.6 ± 5.1 % fat) with 3.0 ± 1.0 years of resistance training experience and a training frequency of 4.3 ± 0.9 days per week. Recruitment centered largely upon university physical activity classes as well as local gyms and fitness centers. A resistance training questionnaire was used to assess each subject’s resistance training background, which consisted of five multiple choice questions regarding frequency of training, length of training (years) overall intensity used during each workout, and current involvement with lower body training. This procedure was completed for inclusion criteria and participants were considered resistance trained if they had completed a minimum of three days of resistance training per week for at least 3 years or more which included some combination of lower body resistance exercise, team sport participation or regular participation in endurance exercise such as running or cycling. All participants were previously resistance-trained, had similar resistance training experience and were currently not participating in regular aerobic exercise. In addition, each subject was required to read and sign an IRB-approved informed consent document and complete a physical activity readiness questionnaire (PAR-Q). Participants were further asked to: 1) avoid changes in their diet and medication use (both over-the-counter and prescription). In particular, non-steroidal anti-inflammatory drugs, cox-2 inhibitors, or acetaminophen were strictly forbidden within the first 72 hours of completing the first and last workout, 2) abstain from intense, unfamiliar physical activity for 48 hours prior to each testing session, and 3) avoid caffeine or nicotine use 12 hours prior to each exercise session. To minimize any confounding impact of other exercise stimuli, all participants were required to abstain from any training of the lower body, (including running, cycling, jogging, etc) outside the intervention for the duration of the study and all other forms of training were to remain consistent throughout the intervention.

Exclusion criteria for this study were those participants diagnosed with or being treated for any cardiovascular, renal, metabolic, hepatic, immunological, orthopedic, psychological, pulmonary, respiratory, or musculoskeletal disorder. Individuals who took any dietary supplements or performance-enhancing drugs known to increase resistance-training performance (i.e. creatine or anabolic agents) with the exception of a multi-vitamin and dietary protein were excluded. Participants who regularly took any non-steroidal anti-inflammatory drugs (i.e., ibuprofen, aspirin, etc.) and those individuals that were sedentary were also excluded. Finally, all females were excluded from this study due to the monthly physiological and hormonal changes that occur which can induce a confounding influence, specifically their impact on muscle damage (46, 50).

Procedures

Eccentric Exercise Protocol

To reduce the impact of confounding variables associated with the completion of other forms of activity, all participants were required to abstain from any additional resistance training activities using the lower body outside the study protocol for the duration of the study and all other forms of training were to remain consistent throughout the intervention. Using a two-day per week training protocol over a four-week period, all study participants completed eight workouts consisting of four sets of six repetitions with varying durations of eccentric contractions. All repetitions were completed using a plate-loaded barbell Smith squat exercise with a resistance level that equated to 80 – 85% 1RM. All workouts were separated by 72 hours meaning that all participants followed either a Monday-Thursday, Tuesday-Friday or Wednesday-Saturday approach. All exercise training sessions occurred at approximately the same time each day, and each repetition was supervised by trained investigators using a metronome to assist with the correct phase for each repetition. All study participants were randomized into one of three training groups. The first group was considered a control group (2S) and completed all repetitions using a traditional concentric-eccentric contraction pattern (two-second concentric, one-second pause, two-second eccentric). A second group (4S) completed all workouts using a similar contraction pattern while incorporating a four-second eccentric contraction (two-second concentric, one-second pause, four-second eccentric). The third and (6S) completed all workouts using a similar contraction pattern while incorporating a six-second eccentric contraction (two-second concentric, one-second pause, six-second eccentric contraction). No rest was allowed between each repetition and a rest period of three minutes was observed between completed sets. On a workout-by-workout basis, and in the event any study participant was unable to adhere to the prescribed contraction duration, the prescribed load was reduced by 10% and all remaining repetitions were completed at the revised resistance level and at the same contraction duration.

Nutritional Control

No specific control over dietary habits was employed for this study protocol. Prior to beginning the protocol, all participants completed four-day (three week days, one weekend day) dietary records by recording all food and beverage consumed. All participants were asked to avoid changes to their diet and were strictly forbidden from adding any dietary supplements or adopting any dietary strategy that might impact their muscle's response to all workouts and the associated training adaptations. All data was entered into a freely available online nutrition database for determination (MyFitnessPal) of average energy and macronutrient intake. It was highly recommended that study participants adhered to and consumed a diet that was easy to replicate and was a typical representation of their normal diet. Copies of all dietary logs were made and provided to the participants for them to replicate their diet leading up to each testing session. The night prior to those study visits, subjects were advised to eat no later than 2200 hours and abstain from caffeine, nicotine or alcohol use for a 24-hour period of time. Participants were also advised to abstain from intense, unfamiliar physical activity and exercise for 48 - 72 hours prior to each testing session.

Body Composition and Anthropometry

For descriptive purposes only, a standard stadiometer was used to record the participants' height in centimeters and weight was measured in pounds (lbs), and converted to kilograms (kg's). Following height measurement, the participants' body fat percentage was determined before the completion of the four-week eccentric training period using skinfold calipers (Lange).

The sum of three skinfold sites (chest, abdomen and thigh) was used to estimate body density (27) before being converted to percent body fat using the Brozek equation. (4) All measurements were taken on the right side of the body and read to the nearest 0.5mm (Beta Technology, Cambridge Maryland). A minimum of two measurements were taken at each site using rotational order with the skin dry and lotion free. If the values varied by more than 2 mm, additional measurements were taken.

One Repetition Maximum (1RM) Testing

A one-repetition maximum was performed by all study participants before (pre), midway through and after (post) the eccentric training program (9). All 1RMs were determined using a standard barbell Smith squat exercise. 1RM testing began with two sets of ten repetitions using a resistance that equates to 50% of self-reported 1RM before completing an additional warm-up set at 80% of self-reported 1RM. Using standard NSCA guidelines (1), the load was increased 10-20% using one-repetition sets until only one successful repetition was completed. To minimize any negative influence of fatigue, each participant's 1RM was determined in approximately three to five 1RM attempts. A lift was deemed successful if a squat repetition was performed to a depth of an 80-90° knee angle and confirmed by visual inspection with trained investigators. The greatest load lifted without assistance and through a full range of motion was recorded as the subject's 1RM. Subjects were instructed not to train for at least 48 hours prior determining their 1RM. To minimize the influence of a learning effect on 1RM performance, study participants completed a familiarization session prior to beginning the training program where they were required to determine their 1RM according to study protocol.

Power Production and Testing

To determine peak and average power production and peak velocity of movement, a Tendo Power and Speed Analyzer (TENDO PSA 310, Europe, Slovak Republic; Software Version- multi-station Net-V-104) was used and attached to the barbell with an extended nylon cord and Velcro strap. The Tendo unit was placed on the floor in a position that allowed the cord to be extended perpendicular to the floor during the Smith squat exercise movement in accordance with the Tendo weightlifting analyzer. To calculate power, the amount of resistance placed upon the bar and lifted (kg's) was entered into the software and using the data in conjunction with the distances traveled and time required to traverse the distance, power was estimated. Using proper squatting technique and a resistance equating to approximately 45% 1RM (30), participants completed three sets of five jump squat repetitions. A rest period of three minutes was observed between sets (49).

Subjects were instructed to hold a bar of the corresponding weight (45%1RM) on their shoulders in the back squat position. Performance of the jump squat for measuring power production involved lowering the bar to the point where the knee angle was approximately 100° as measured by a goniometer. After reaching the bottom of the movement, participants were instructed to immediately jump upward as fast as possible with their feet leaving the ground while holding the bar tightly to the shoulders for five consecutive repetitions. Each subject was allowed multiple practice repetitions with immediate feedback from the investigators to maintain safe and proper technique. Peak velocity generated during the concentric phase of each repetition was recorded by the Tendo unit as well as the repetition(s) responsible for generating the greatest power output.

Perceived Soreness

Prior to, as well as 0, 24, 48, and 72 hours after the first and last workout of the eccentric protocol, subjects were asked to assess their perceived level of muscle soreness using a visual-analog scale. Soreness was evaluated along a 10 cm scale (0 cm = no soreness, 10 cm = extreme soreness) at all indicated time points by drawing a line perpendicular to the continuum line extending from 0 to 10 cm. The distance of each mark was measured from zero and rounded up to the nearest one-tenth of a centimeter. This method of assessing perceived soreness has been used in a number of previous investigations and is commonly accepted for this purpose (8, 28).

Vertical Jump

Prior to completing the first workout, and after the final workout, vertical jump height was assessed. The Vertec (Jump USA, Sunnyvale, CA) is used to assess vertical jump height by measuring the difference between the fully extended standing reach height and the maximal vertical jump and reach height. The reach height for the Vertec was established using a body position of an erect stance, both feet together and flat on the ground, both arms fully extended overhead, and with the head and eyes in a neutral position. The subjects were instructed to perform a counter-movement jump that required participants to begin in an upright position with the feet parallel to each other and hip to shoulder width apart. Upon a verbal cue from trained investigators, subjects performed a rapid countermovement by flexing the knees and hips. After the subjects attained their chosen depth of descent, they explosively extended at the hips, knees and ankles to achieve a maximal jump height at the highest peg they could touch. After the initial description of the counter-movement jump, subjects were provided two warm-up jumps. Study participants then completed three maximal-effort jumps with a one-minute rest period between each jump attempt. The best of three trials was recorded.

STATISTICAL ANALYSIS

Using the SPSS 20.0 statistical software package (SPSS Inc., Chicago, IL), two-way mixed factorial ANOVA (group x time) with repeated measures on time were utilized to determine main and interaction effects on all measured dependent variables. When a significant group x time interaction was obtained for any dependent variable, the statistical model was assessed by examining the simple main effects with separate within- group repeated measures ANOVA and appropriate t-tests for each time point. For all analyses, an alpha-level of 0.05 was used to determine statistical differences between group means. When the sphericity assumption was not met, the Huynh-Feldt correction factor was applied to the entire model. Normality was confirmed using visual inspection of standardized skewness and kurtosis scores and Shapiro-Wilk tests. Sample size was determined *a priori* using an average effect size of 1.56, alpha level of 0.05, and power (1- β) of 0.8 from previously published data (15). All data are presented as means ± SD. For data collected using the TENDO power analyzer, collected values were averaged and recorded as the average of the three completed sets for peak power, average power and peak velocity. For the soreness data, separate 2 x 5 (week x time) mixed factorial ANOVA's were completed individually by group. When a significant group x time interaction effect was found, paired t-tests were used to determine statistical significance between each respective time point.

RESULTS

<u>Demographics and Dietary Information</u>

Baseline data for age, height (cm), weight (kg), body composition (fat %), and standing reach (cm), training experience (years), training frequency (days/week), one-repetition maximum (kg) and all dietary data (energy, carbohydrates, protein and fats) are all presented in table 1. As determined using one-way ANOVA, no significant differences ($p>0.05$) at baseline were found for all variables with the exception of absolute (grams/day) protein intake ($p =0.03$). Tukey's post-hoc tests revealed that the 4S group (214 ± 70 grams) consumed significantly more protein than the 2S group (133 ± 44 grams, $p = 0.02$) but not the 6S group (166 ± 68 grams, $p = 0.20$). Forty participants were randomized into the study, but ten participants failed to complete the investigation due to non-compliance, thus all these data were removed from analysis. Therefore, a remaining total of thirty subjects completed the study including all familiarization and pretesting sessions, all eccentric training bouts, and all post-testing sessions, with no subjects missing any training sessions. In addition, no injuries or major adverse events occurred for any participant throughout the entire intervention. Training progressions for all workouts, sets, reps, % load over the 4-week training period are presented in table 2.

<<< Insert Table 1 about here >>>

<<< Insert Table 2 about here>>>

<u>One-Repetition Maximum (1RM)</u>

The group x time interaction effect for 1RM was not statistically significant ($p= 0.31$). There was a significant time effect ($p < 0.001$) for 1RM strength as the 2S (Week 0: 124 ± 20 vs. Week 4: 135 ± 23 kg, $p = 0.007$), 4S (Week 0: 129 ± 22 kg vs. Week 4: 146 ± 30 kg, $p < 0.001$) and 6S groups (Week 0: 118 ± 17 kg vs. Week 4: 133 ± 17 kg, $p < 0.001$) all experienced significant increases in maximal strength (Figure 1).

<<<Insert Figure 1 about here>>>

<u>Vertical Jump</u>

The group x time interaction effect for vertical jump did not reach significance but there was a trend towards a difference ($p = 0.07$) and a significant main effect for time was found (p =

0.004). Within group analysis of each eccentric duration group revealed that the 2S group (Week 0: 66 ± 11 vs. Week 4: 69 ± 11 cm, $p = 0.02$) reached statistical significance while the 4S (Week 0: 69 ± 9 vs. Week 4: 70 ± 9 cm, $p = 0.40$) and 6S groups (Week 0: 61 ± 9 vs. Week 4: 62 ± 9 cm, $p = 0.30$) groups both did not (Table 3).

Peak Power, Mean Power and Peak Velocity

Peak power, mean power and peak velocity values from all three completed sets were first averaged prior to statistical analysis using a two-way mixed factorial (group x time) ANOVA. No group x time interaction effect for peak power was determined ($p = 0.65$). A significant main effect of time ($p < 0.001$) for peak power was found with each group experiencing a statistically significant increase ($p < 0.005$) across the 4-week eccentric training program. A significant group x time interaction effect was found for changes in peak velocity ($p = 0.04$) with no overall main effect for time ($p = 0.29$). Follow-up within-group analysis revealed that the 2S ($p = 0.19$) and 4S ($p = 0.29$) groups did not experience statistically significant changes in peak velocity while the 6S group did experience a statistically significant reduction ($p = 0.03$) in peak velocity when performing the jump squat protocol. Average power values also revealed no significant group x time interaction ($p = 0.43$). Again, a significant main effect over time was found ($p < 0.001$) indicating that all groups experienced a significant increase in average power production throughout the jump squat protocol. Within-group analysis over time revealed that all three groups experienced significant ($p < 0.005$) increases in average power production.

<<< Insert Table 3 about here >>>

Soreness

At week 0 and week 4, all groups (2S, 4S and 6S) experienced significant within-group ($p < 0.05$) increases in self-reported soreness values. As seen in figure 2, the 2S group reported a significant ($p = 0.002$) group x time interaction effect between week 0 and week 4 soreness values. Separate paired t-tests at each respective time point (pre-exercise, post-exercise, 24 h post-exercise, 48 h post-exercise and 72 h post-exercise) revealed significant differences ($p < 0.05$) between the week 0 and week 4 at the following time points: post-exercise ($p = 0.03$), 24 h post-exercise ($p = 0.01$), 48 h post-exercise ($p = 0.01$) and 72 h post-exercise ($p = 0.04$). As seen in figure 3, the 4S group reported a significant ($p < 0.001$) group x time interaction effect between week 0 and week 4 soreness values. Separate paired t-tests at each respective time point (pre, post, 24 h post, 48 h post and 72 h post) revealed significant differences ($p < 0.05$) between the week 0 and week 4 at the following time points: 24 h post-exercise ($p = 0.01$), 48 h post-exercise ($p = 0.01$) and 72 h post-exercise ($p = 0.04$). Finally, as seen in figure 4, the 6S group reported a significant ($p = 0.034$) group x time interaction effect between week 0 and week 4 soreness values. Separate paired t-tests at each respective time point (pre-exercise, post-exercise, 24 h post-exercise, 48 h post-exercise and 72 h post-exercise) revealed significant differences ($p < 0.05$) between the week 0 and week 4 at the following time points: 48 h post-exercise ($p = 0.046$).

<<<Insert Table 2 and Figures 2, 3 and 4 about here>>>

DISCUSSION

The primary findings of this study indicate that a 4-week training period consisting primarily of eccentric contractions of varying durations can significantly increase maximal strength and vertical jump as well as peak and average power production throughout a jump squat protocol. We are the first study to investigate the effects of different durations of eccentric contractions on these variables. When looking closely at the impact of contraction speed, most work has centered upon the entire eccentric-concentric contraction of varying speeds with little to no work focused upon the specific impact of altering the contraction speed and/or duration of only part of the contraction cycle (concentric only or eccentric only). Considering prior research has demonstrated positive outcomes of eccentric exercise training, this topic permitted examination of the role of different eccentric contraction durations and its impact on exercise performance.

Our maximal strength data revealed that while no interaction was found to indicate one specific eccentric duration group (2S, 4S, or 6S) against the other, all eccentric contraction durations did significantly increase 1RM by 8.9 – 13.2% over the 4-week training period. While no other data exist that has specifically manipulated the eccentric contraction speed using a floor-based exercise, other researchers have usedopen-kinetic chain movements in conjunction with an isokinetic dynamometer (23, 32). Previous work using eccentric resistance training has incorporated submaximal, maximal (100% one-repetition maximum (1RM) or supramaximal (typically 105-120% 1RM) training loads to stimulate greater increases in maximal muscle strength in traditional activities involving both concentric and eccentric actions (22, 25, 26, 33, 40), compared to conventional types of strength training (10), or using very light loads (5). In comparison to this previous work, results from the present study are in line with these outcomes. It is important to highlight that the present study used a load assignment of 80 – 85% 1RM and thus was not maximal. It is our contention that this is a meaningful practical find, particularly when we report positive improvements in maximal strength, vertical jump and power production (Table 3).

Our work supports the results from a number of previous studies that show increases in power as a result of eccentric exercise training (42, 43). Optimal power production serves as an important part in nearly all aspects of sports, and is critical throughout various parts of the stretch-shortening cycle (48). Optimal power production has been shown to be an effective modality in increasing (explosive) muscle strength, muscle cross-sectional area, leading to increased sarcomere length (6, 11, 17, 22, 48). From a power perspective, findings from our data reveal a significant increase in vertical jump in the 2S group but not the 4S or 6S group, and significant increases in all three groups for both peak power and average power. The load and volume used to assess power output from our jump squat protocol was 45% 1RM, a value that has been previously shown to align with optimal power production (30). In support of the chosen load, for traditional resistance exercises, Siegel (45) reported maximal power output with loads of 50 – 70% of 1RM for the squat and 40 – 60% of 1RM for the bench press. Similarly, studies from Cormie (12-14) found that the optimal loads were 0% of 1RM for the jump squat, 56% of 1RM for the squat, and most recently 40% for jump squats(30).

Peak velocity was the only variable to highlight a significant group x time interaction effect ($p = 0.04$), and it was interesting to find that no changes occurred for peak velocity in the 2S and 4S groups, but peak velocity actually decreased in the 6S group after the 4-week training program (Table 3). In a similar respect, our reported changes in vertical jump approached statistical significance for the group x time interaction ($p = 0.07$), and upon a closer look only the 2S group experienced a statistically significant improvement in their vertical jump performance while the 4S and 6S groups both experienced non-significant improvements in vertical jump (Table 3). Further, earlier work by Enoka (18) reported that the increased forces associated with eccentric contractions are due to specific activation strategies employed by the nervous system, while numerous mechanisms of enhanced force production and neural control have been recently proposed in eccentric muscle contractions (16, 21). With respect to eccentric training and power output, recent investigations by Cook et al (11) utilized three weeks of eccentric training combined with over speed exercises in trained athletes and found the eccentric training block resulted in greater improvements in countermovement jump peak power when compared with traditional training. Similar results were also shown by Sheppard et al. (42) who investigated jump training exercises three times per week for 5 weeks on high-performance male and female volleyball players. Additional loads were applied during the eccentric but not concentric phase of countermovement jumping exercises. In total, both intervention and control groups performed 190 jumps within the 5-wk training period, in addition to other strength training exercises. The eccentric accentuated training group improved jump performance by 11% whereas there was no effect (2%) in the control group. While these previous reports provide support for the overall changes we found, data are lacking that clearly points towards the different patterns of eccentric contraction duration as what was prescribed in the present study.

Interestingly, the 6-second eccentric group experienced a significant reduction in peak velocity during the jump squat while the 2-second and 4-second groups did not. We speculate this may be manifested by a greater time under tension experienced by the muscle contractile apparatus throughout the training sessions. While time under tension is considered a primary mechanism for changes in overall muscle hypertrophy, the increased work generated by the musculoskeletal system during eccentric muscle contractions, especially at longer durations may not be optimal when trying to enhance peak velocity and greater concentric speeds of contraction. During an eccentric contraction, muscle absorbs energy developed by an external load. Therefore, during an eccentric muscle action, the shock absorber-spring-component of the muscle tendon system contributes energy to the forces produced. In this regard, another proposed mechanistic explanation of the reduction in peak velocity in the 6-second group entails that of the stretch-shortening cycle (SSC). While the SSC is considered an important component in muscle force generation and eccentric activity (48), and due to the time component function during the SSC, it could be that the coupling time between the eccentric and concentric phase during SSC from the longer eccentric duration may have been too long. Specifically, any elastic energy was lost as heat thereby not being able to contribute to force generating capacity.

Further, the 2-second group experienced an increase in vertical jump height while the 4-second and 6-second group did not. We associate this to the principle of specificity as subjects in the 2-second group and those who may participate in explosive types of activities often experience similar patterns of eccentric contraction time needed for a specific movement. As previously mentioned, Sheppard et al. (42) investigated jump training exercises three times per week for five weeks on high-performance male and female volleyball players. Additional loads were applied during the eccentric but not concentric phase of countermovement jumping exercises, Overall, both intervention and control groups performed 190 jumps during the 5-wk training period, in addition to other strength training exercises. The eccentric accentuated training group improved jump performance by 11% while there was no change in the control group.

Certainly, a coach or athlete may view the changes for each group relative to vertical jump or peak velocity production as an unfavorable outcome, but these results are not surprising when considering the specificity principle of exercise training. While no data are available that perfectly aligns with our work, other outcomes can help in better understanding these outcomes. For example, recently, Wirth et al (52) analyzed the effects of an eccentric strength training protocol using supra-maximal loads on different maximal and explosive strength parameters of the lower extremity, and tested eccentric maximal strength, maximal isometric strength (MVC), 1RM, explosive strength (RFD), countermovement jump (CMJ) and squat jump (SJ) before and after 6 weeks of training. The training group was composed of 15 individuals with limited weight training experience and a control group of 13 subjects, also with limited weight training experience. The lower body was trained three days per week using a 45-degree leg press. Each training session comprised 5 sets of 3 repetitions with a 6-min rest between each set. After 6 weeks, a significant increase in eccentric max strength (28.2%) and 1RM (31.1%) were found in the experimental group who trained with supra-maximal loads.. The increases observed in the control group showed non- significant changes. Although the changes in MVC, RFD and vertical jump heights were not significantly different in both groups, unlike in our present study, it does shed more light on potential outcomes of these training variables with respect to eccentric training.

In light of these findings, one might want to be cognizant of this potential outcome with respect to vertical jump and peak velocity and program design. Similarly for those interested in increasing vertical jump, coaches and athletes need to be aware of the possible impact of longer contraction durations and their potential ability to make the muscle slower. Certainly for some sports or positions this might be favorable, regardless, this is an important consideration and one that needs future research to provide more information. In this respect, our work is the first study to examine the effects of eccentric contraction durations that include vertical jump and power output measures. While numerous training methods and programs are used to enhance vertical jump and power output, we encourage strength and conditioning coaches and fitness professionals to utilize aspects of eccentric contraction durations throughout the yearly training cycle to further promote aspects of sports performance and to further understand how manipulating the eccentric component can go on to impact strength, power and vertical jump performance.

Strengths of our study design center mostly upon the practical considerations to strength and conditioning and fitness professionals as we completed this investigation. As such, our chosen eccentric load while lighter than maximal and supra maximal eccentric techniques commonly employed (29), it accomplished a few important outcomes. First, all of our participants got stronger, jumped higher and produced more power (Table 3). Second, the loading program we employed (4 x 6 reps @ 80 – 85% 1RM) could serve as an excellent guide for a coach or trainer who wants to prescribe eccentric work. Third, this load allowed for a single athlete to complete nearly all repetitions on their own without help or a spot (2-second group), with the exception of some repetitions towards the latter part of sets, particularly in the 4S and 6S groups. This is an important consideration for a coach who may have previously employed maximal eccentric work that would require multiple spotters and would allow much more time to complete a single set and a complete workout. Another strength of our workout was that every repetition was directly supervised and strictly monitored for appropriate squatting technique and compliance to the prescribed contraction duration. While limited data existed to guide us as to how to program our workouts, we feel that a single workout consisting of a 2, 4 or 6-second duration while completing 4 sets of 6 repetitions at a load of 80 – 85% 1RM could serve as an optimal starting point for most athletes and coaches. Overall, this is an important consideration for strength and conditioning professionals who choose to implement eccentric contraction durations into their programs, as using either a 2,4, or 6-second eccentric duration is likely to initiate favorable adaptations from a strength and power perspective.

There were some limitations to this study that deserve attention. Our data are best extrapolated to young, healthy and previously trained males. While this population is arguably the most likely to employ eccentric training, other populations such as older individuals, females, rehabilitation patients and other clinical populations may or may not respond in the same manner as our study cohort. Second, our chosen measure of muscle strength was the barbell Smith squat exercise. We recognize that some individuals may perceive this as a less practical exercise and may not extrapolate well to other sports-related activities. However, we would like to emphasize that in the attempt to incorporate eccentric training, we prioritized the use of a closed kinetic chain movement that engaged multiple joints across the lower body in a movement pattern that has practical application to sport performance as opposed to a single joint, open kinetic chain movement that has been used in previous studies (19, 23). We recognize that utilizing a movement such as the free bar back (or front) squat might be preferred by many, but these lifts using this type of training could invoke greater levels of physical risk that we felt were not justified. This is particularly important when considering that limited data exist to document whether controlled manipulation of eccentric contraction duration would instigate favorable resistance training adaptations. For these reasons, we chose the Smith Squat exercise to limit potential injury, and to have greater control over technique. Third, our measured changes of strength, power measures, and soreness, were limited only to the measurement times outlined in this protocol. While the current study was limited to four weeks of training, strength and conditioning professionals can prescribe two, four or six second eccentric durations for any part of the yearly training cycles, and especially during off-season play to further promote increases in strength, power and hypertrophy.

An interesting note to share with readers is that although all groups performed the same amount of volume over the course of the study, (4 x 6 reps) and while a metronome was used by trained investigators to ensure all prescribed contraction duration parameters were followed, the chosen percent range (80-85%1RM) required load adjustments for many in the 4S and 6S groups, as subjects were unable to complete the necessary sets and reps for their prescribed eccentric duration. Specifically, many participants in the 4S group and all participants in the 6S group required a load reduction of 10% in order for all remaining repetitions and sets to be completed at the revised resistance level and at the same contraction duration. This adjustment was made at the start of the first workout to allow all subjects to complete the first workout, and most commonly at the beginning of workout #5 after re-establishment of the subject's 1RM. While this reduction and load adjustment may not pose a limitation per se, it is our contention that when prescribing eccentric contraction durations for 4 and 6 seconds, we suggest strength and conditioning and fitness professionals take a more conservative approach for loading parameters (i.e. 65-70% 1RM) in order for their athletes and clients to adhere to the prescribed contraction duration for a given training session, particularly if they are choosing to utilize a 4-second or 6-second contraction duration. Further, it is important for strength and conditioning and fitness professionals to recognize these findings to allow future investigations to future explore any acute manipulation of training variables and how they may impact overall changes in performance, particularly with volume and even rest periods. As an example, we chose to follow NSCA guidelines for rest with strength related loading patterns and reducing the rest interval would have made it extremely challenging for the study participants in the longer eccentric durations (4S and especially 6S) to complete a program with a similar volume and intensity. Lastly, some strength and conditioning coaches might prefer to use a forced repetition approach with spotters as opposed to stopping the set and adjusting the load as was completed in the present study. While this approach brings in subtle differences we feel the differences are minor and that many athletes would respond positively to either approach (stopping and adjusting load vs. completing forced repetitions with spotters). Notably and from a practical perspective, use forced repetition would likely be more time efficient, an attribute likely of great interest to a strength and conditioning coach.

Previous work by Seger (41) examined the effects of eccentric versus concentric training on thigh muscle strength and EMG. Two groups of young healthy adult men performed 10 weeks of either eccentric or concentric unilateral isokinetic knee extensor training at 90 degrees, 4 sets of 10 maximal efforts, 3 days a week. Changes in strength of the trained legs revealed more signs of specificity related to velocity and contraction type after eccentric when compared to concentric training. No major training effects were present when observing eccentric to concentric ratios of agonist EMG activity or in relative antagonist (hamstring) activation. Thus, for the trained leg, the muscle action type and speed specific changes in maximal voluntary eccentric strength could not be related to any effects on neural mechanisms, such as a selective increase in muscle activation during eccentric actions. Although both types of training elicited cross-education effects, that is, action type and velocity specific increases in strength occurred in the contralateral, untrained, leg, accompanied by a specific increase in eccentric to concentric EMG ratio after eccentric training. Similar results were also recently reported by Carvalho (7). While a number of differences exist between our work and these data, it does provide an indication that capturing such information as part of training programs may be helpful. Nonetheless, it could have provided a deeper look into the skeletal muscle response to the eccentric manipulation of our training program, and as a result it is recommended that future investigations employ such approaches.

In conclusion, results from a four-week resistance training program involving the Smith squat exercise that emphasized eccentric contractions of varying duration showed significant increases in maximal strength, vertical jump, peak and average power and peak velocity. All study participants tolerated the exercise program well and consequently, coaches and athletes are encouraged to look at the parameters of our work and program their own eccentric programs in an attempt to achieve similar outcomes. While much more research is needed to better understand how to best prescribe and program eccentric exercise, results from the present study are an appropriate first step.

PRACTICAL APPLICATIONS

In recent years, the interest level of strength and conditioning professionals in the incorporation of varying levels of eccentric exercises has increased. In light of this interest, the present study was designed to provide data using a floor-based (closed-kinetic chain), multi-joint movement at assigned loads that an athlete could safely complete on their own with a single spotter. For these reasons, we feel that strength and conditioning professionals who develop programs with the intention to increase muscle strength and power output from eccentric muscular contractions will find a number of important conclusions from this study. Eccentric muscular contractions require greater work and effort on the musculoskeletal system throughout a given range of motion and for any given exercise. From this consideration alone, coaches and strength and conditioning professionals should be cognizant of the overall readiness level of an athlete and determine to what extent an athlete may be able to complete such training. Even in the face of our relatively short training program and incorporation of just one exercise, our data provide outcomes suggestive of favorable adaptations to strength, power, velocity and vertical jump in all groups. In this respect, these data are the first to demonstrate to coaches and athletes how altering the duration of eccentric contraction can impact how an athlete is able to adapt from a strength and power perspective. Moreover, results from our work also inform coaches of how to prescribe eccentric activity as part of a greater training cycle. In this respect, our findings inform strength and conditioning coaches and fitness professionals how to better understand the expressions of strength and power in response to changing durations of eccentric activity. Most importantly these data can inform training programming and show how a group of young, healthy males with previous resistance training experience are able to respond. Further to this point, we contend that a load of 80 – 85% 1RM at an assigned work output of 4 x 6 reps operates as a reasonable "upper limit" of what an athlete can handle on their own and successfully (and safely) complete the workout. Many of our subjects required that we reduce the load throughout some point of the workout in the 4S and 6S groups, but the 2S group responded without a need for a load change. Lastly, our soreness data provide indications for coaches on how to potentially assign an eccentric workout to effectively minimize soreness and muscle damage. Finally, additional well-controlled eccentric training studies on trained populations are needed using similar movement patterns as well as different movement patterns (upper vs. lower) to expand the understanding of the underlying mechanisms that impact strength and power expression and development.

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References

1. Baechle TaER. National Strength and Conditioning Association (NSCA) Essentials of Strength Training and Conditioning. 3nd ed. Human Kinetics. Champaign, IL 2008., 2008.
2. Barry BK, Warman GE, and Carson RG. Age-related differences in rapid muscle activation after rate of force development training of the elbow flexors. Exp Brain Res 162: 122-132, 2005.
3. Blazevich AJ, Horne S, Cannavan D, Coleman DR, and Aagaard P. Effect of contraction mode of slow-speed resistance training on the maximum rate of force development in the human quadriceps. Muscle Nerve 38: 1133-1146, 2008.
4. Brozek J, Grande, F., Anderson, J. T., & Keys, A. . Densitometric analysis of body composition: Revision of some quantitative assumptions. Annals of the New York Academy of Sciences 110: 113-140, 1963.
5. Burd NA, West DW, Staples AW, Atherton PJ, Baker JM, Moore DR, Holwerda AM, Parise G, Rennie MJ, Baker SK, and Phillips SM. Low-load high volume resistance exercise stimulates muscle protein synthesis more than high-load low volume resistance exercise in young men. PLoS One 5: e12033, 2010.
6. Carothers KC, Kyle F; Alvar, Brent A; Dodd, Daniel J; Johanson, Jeremy C; Kincade, Brian J; Kelly, Stephen B. Comparison Of Muscular Strength Gains Utilizing Eccentric, Standard And Concentric Resistance Training Protocols. J Strength Cond Res 24, Jan 2010.
7. Carvalho A, Caserotti P, Carvalho C, Abade E, and Sampaio J. Effect of a short time concentric versus eccentric training program on electromyography activity and peak torque of quadriceps. Journal of human kinetics 41: 5-13, 2014.
8. Clarkson PM, Nosaka K, and Braun B. Muscle function after exercise-induced muscle damage and rapid adaptation. Med Sci Sports Exerc 24: 512-520, 1992.
9. Coburn J, Mahlek, MH. National Strength and Conditioning Association (NSCA) Essentials of Personal Training. 2nd ed. Human Kinetics. Champaign, IL 2012., 2012.
10. Colliander EB and Tesch PA. Effects of eccentric and concentric muscle actions in resistance training. Acta Physiol Scand 140: 31-39, 1990.
11. Cook CJ, Beaven CM, and Kilduff LP. Three weeks of eccentric training combined with overspeed exercises enhances power and running speed performance gains in trained athletes. J Strength Cond Res 27: 1280-1286, 2013.
12. Cormie P, McBride JM, and McCaulley GO. Validation of power measurement techniques in dynamic lower body resistance exercises. J Appl Biomech 23: 103-118, 2007.
13. Cormie P, McCaulley GO, and McBride JM. Power versus strength-power jump squat training: influence on the load-power relationship. Med Sci Sports Exerc 39: 996-1003, 2007.
14. Cormie P, McCaulley GO, Triplett NT, and McBride JM. Optimal loading for maximal power output during lower-body resistance exercises. Med Sci Sports Exerc 39: 340-349, 2007.

15. Doan BK, Newton RU, Marsit JL, Triplett-McBride NT, Koziris LP, Fry AC, and Kraemer WJ. Effects of increased eccentric loading on bench press 1RM. J Strength Cond Res 16: 9-13, 2002.
16. Duchateau J and Baudry S. Insights into the neural control of eccentric contractions. J Appl Physiol (1985) 116: 1418-1425, 2014.
17. Elmer S, Hahn S, McAllister P, Leong C, and Martin J. Improvements in multi-joint leg function following chronic eccentric exercise. Scand J Med Sci Sports 22: 653-661, 2012.
18. Enoka RM. Eccentric contractions require unique activation strategies by the nervous system. J Appl Physiol (1985) 81: 2339-2346, 1996.
19. Farthing JP and Chilibeck PD. The effect of eccentric training at different velocities on cross-education. Eur J Appl Physiol 89: 570-577, 2003.
20. Hather BM, Tesch PA, Buchanan P, and Dudley GA. Influence of eccentric actions on skeletal muscle adaptations to resistance training. Acta Physiol Scand 143: 177-185, 1991.
21. Herzog W. Mechanisms of enhanced force production in lengthening (eccentric) muscle contractions. J Appl Physiol (1985), 2013.
22. Higbie EJ, Cureton KJ, Warren GL, 3rd, and Prior BM. Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. J Appl Physiol (1985) 81: 2173-2181, 1996.
23. Hollander DB, Kraemer RR, Kilpatrick MW, Ramadan ZG, Reeves GV, Francois M, Hebert EP, and Tryniecki JL. Maximal eccentric and concentric strength discrepancies between young men and women for dynamic resistance exercise. J Strength Cond Res 21: 34-40, 2007.
24. Hortobagyi T, Barrier J, Beard D, Braspennincx J, Koens P, Devita P, Dempsey L, and Lambert J. Greater initial adaptations to submaximal muscle lengthening than maximal shortening. J Appl Physiol (1985) 81: 1677-1682, 1996.
25. Hortobagyi T, Devita P, Money J, and Barrier J. Effects of standard and eccentric overload strength training in young women. Med Sci Sports Exerc 33: 1206-1212, 2001.
26. Hortobagyi T, Hill JP, Houmard JA, Fraser DD, Lambert NJ, and Israel RG. Adaptive responses to muscle lengthening and shortening in humans. J Appl Physiol (1985) 80: 765-772, 1996.
27. Jackson AS and Pollock ML. Generalized equations for predicting body density of men. Br J Nutr 40: 497-504, 1978.
28. Kerksick CM, Kreider RB, and Willoughby DS. Intramuscular adaptations to eccentric exercise and antioxidant supplementation. Amino Acids 39: 219-232, 2010.
29. Mike J, Kerksick, CM, Kravitz, L. How to Incorporate Eccentric Training Into a Resistance Training Program. Strength and Conditioning Journal. 37 (1): 5-17. February 2015. How to Incorporate Eccentric Training Into a Resistance Training Program. . Strength Con J 37: 5-17, 2015.
30. Moir GL, Gollie JM, Davis SE, Guers JJ, and Witmer CA. The effects of load on system and lower-body joint kinetics during jump squats. Sports Biomech 11: 492-506, 2012.
31. Newton R.U KWJ. Developing Explosive muscular power: Implications for a mixed methods training strategy. J Strength Cond Res 16: 21-31, 1994.
32. Nickols-Richardson SM, Miller LE, Wootten DF, Ramp WK, and Herbert WG. Concentric and eccentric isokinetic resistance training similarly increases muscular

strength, fat-free soft tissue mass, and specific bone mineral measurements in young women. Osteoporos Int 18: 789-796, 2007.
33. Norrbrand L FJ, Pozzo M, Tesch PA. Eccentric overload appears necessary to optimize skeletal muscle adaptations to chronic resistance exercise. Eur J Appl Physiol 102: 271-281, 2008.
34. Norrbrand L, Fluckey JD, Pozzo M, and Tesch PA. Resistance training using eccentric overload induces early adaptations in skeletal muscle size. Eur J Appl Physiol 102: 271-281, 2008.
35. Nosaka K and Newton M. Concentric or eccentric training effect on eccentric exercise-induced muscle damage. Med Sci Sports Exerc 34: 63-69, 2002.
36. Nosaka K and Newton M. Difference in the magnitude of muscle damage between maximal and submaximal eccentric loading. J Strength Cond Res 16: 202-208, 2002.
37. Roig M, O'Brien K, Kirk G, Murray R, McKinnon P, Shadgan B, and Reid WD. The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. Br J Sports Med 43: 556-568, 2009.
38. Schoenfeld BJ. Does exercise-induced muscle damage play a role in skeletal muscle hypertrophy? J Strength Cond Res 26: 1441-1453, 2012.
39. Schuenke MD, Herman JR, Gliders RM, Hagerman FC, Hikida RS, Rana SR, Ragg KE, and Staron RS. Early-phase muscular adaptations in response to slow-speed versus traditional resistance-training regimens. Eur J Appl Physiol 112: 3585-3595, 2012.
40. Seger JY, Arvidsson B, and Thorstensson A. Specific effects of eccentric and concentric training on muscle strength and morphology in humans. Eur J Appl Physiol Occup Physiol 79: 49-57, 1998.
41. Seger JY and Thorstensson A. Effects of eccentric versus concentric training on thigh muscle strength and EMG. Int J Sports Med 26: 45-52, 2005.
42. Sheppard JM HS, Barker M, Taylor K, Chapman D, and McGuigan M NR. The effect of training with accentuated eccentric Load counter-movement jumps on strength and power characteristics of high-performance volleyball player. Int J Sports Sci Coaching 3: 355-363, 2008.
43. Sheppard JM and Young K. Using additional eccentric loads to increase concentric performance in the bench throw. J Strength Cond Res 24: 2853-2856, 2010.
44. Shepstone TN, Tang JE, Dallaire S, Schuenke MD, Staron RS, and Phillips SM. Short-term high- vs. low-velocity isokinetic lengthening training results in greater hypertrophy of the elbow flexors in young men. J Appl Physiol (1985) 98: 1768-1776, 2005.
45. Siegel JA, Gilders RM, Staron RS, and Hagerman FC. Human muscle power output during upper- and lower-body exercises. J Strength Cond Res 16: 173-178, 2002.
46. Stupka N, Lowther S, Chorneyko K, Bourgeois JM, Hogben C, and Tarnopolsky MA. Gender differences in muscle inflammation after eccentric exercise. J Appl Physiol (1985) 89: 2325-2332, 2000.
47. Stupka N, Tarnopolsky MA, Yardley NJ, and Phillips SM. Cellular adaptation to repeated eccentric exercise-induced muscle damage. J Appl Physiol (1985) 91: 1669-1678, 2001.
48. Vogt M and Hoppeler HH. Eccentric exercise: mechanisms and effects when used as training regime or training adjunct. J Appl Physiol (1985) 116: 1446-1454, 2014.
49. Willardson J. A brief review: How much rest between sets. Strength and Conditioning Journal 30: 44-50, 2008.

50. Willoughby D, Wilborn, CD. Estradiol in females may negate skeletal muscle myostatin mrna expression and serum myostatin propeptide levels after eccentric muscle contractions. Journal Sports Science and Medicine: 672-681, 2006.
51. Willoughby DS, Taylor M, and Taylor L. Glucocorticoid receptor and ubiquitin expression after repeated eccentric exercise. Med Sci Sports Exerc 35: 2023-2031, 2003.
52. Wirth K, Keiner M, Szilvas E, Hartmann H, and Sander A. Effects of eccentric strength training on different maximal strength and speed-strength parameters of the lower extremity. J Strength Cond Res, 2014.

FIGURE LEGENDS

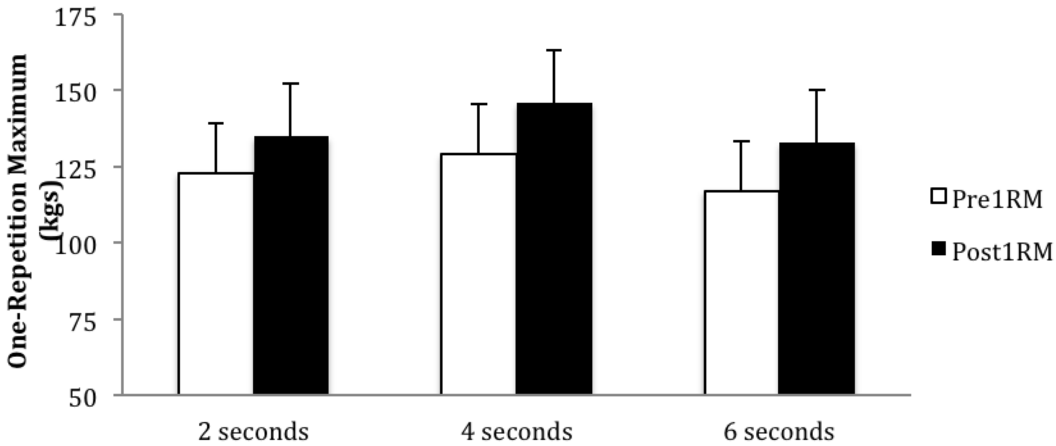


Figure 1: Pre and Post training values for one repetition maximum (kgs) for all groups. Data are means ± SD. n=30

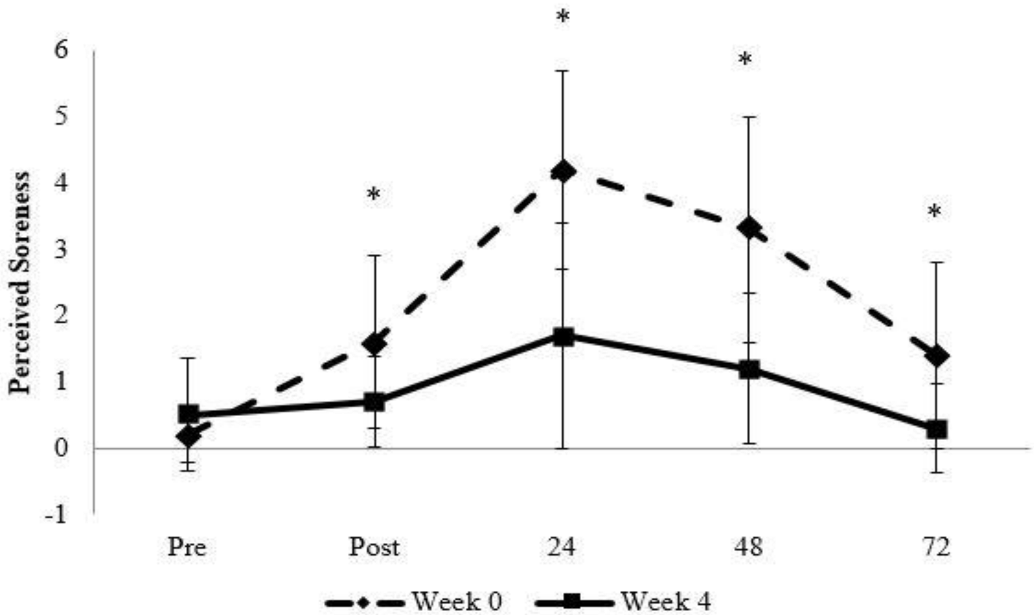


Figure 2: Perceived soreness levels for the 2S (2-second) group from week 0 to week 4. Data are means ± SD. n= 10 * = Week 4 significantly different than week 0 at designated time point, $p < 0.05$.

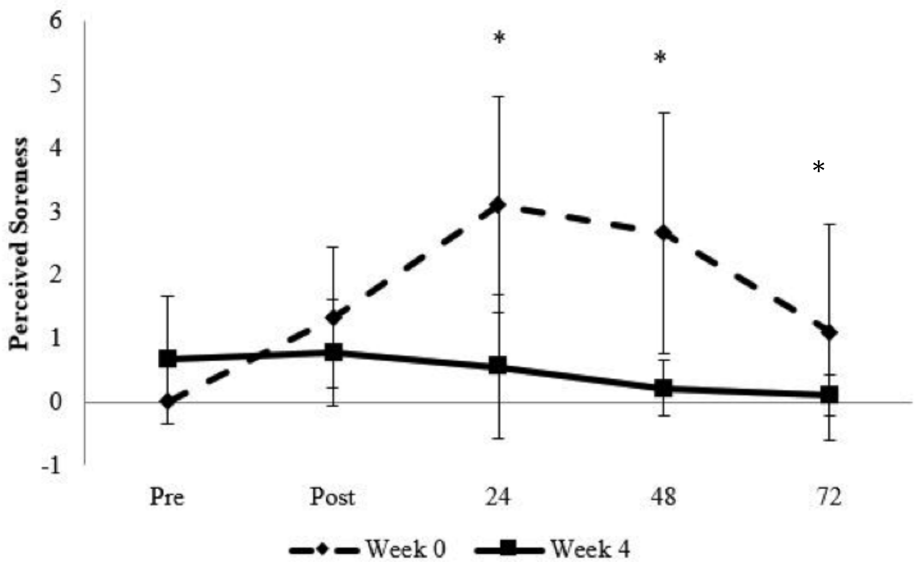


Figure 3: Perceived soreness levels for the 4S (4-second) group from week 0 to week 4. Data are means ± SD. n=9 * = Week 4 significantly different than week 0 at designated time point, $p < 0.05$.

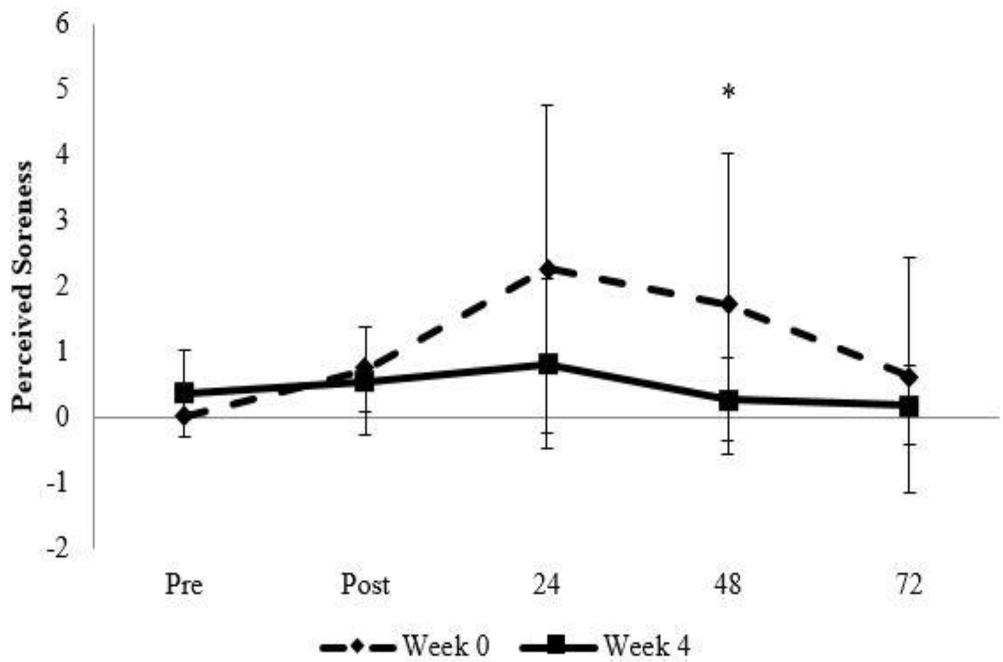


Figure 4: Perceived soreness levels for the 6S (6-second) group from week 0 to week 4. Data are means ± SD. n=11 * = Week 4 significantly different than week 0 at designated time point, $p < 0.05$

Table 1: Descriptive statistics for all study participants (mean ± *SD*).

	2 S (n = 10)	4 S (n = 9)	6 S (n = 11)	All Groups (n = 30)	Sig. (p)
Age (years)	22 ± 2.1	22 ± 2.1	23 ± 4.2	23 ± 3.5	0.21
Height (cm)	180 ± 6.6	176 ± 4.8	178 ± 8.4	178 ± 6.8	0.58
Weight (kg)	79 ± 5.4	82 ± 12.0	85 ± 16.7	82 ± 12	0.57
Body Fat (%)	10.3 ± 3.6	10.5 ± 4.8	13.7 ± 6.0	11.6 ± 5.1	0.23
Standing Reach (cm)	226 ± 9	223 ± 8	228 ± 13	226 ± 11	0.66
Training Experience (years)	3.1 ± 0.9	2.8 ± 1.1	3.1 ± 1.0	3.0 ± 1.0	0.73
Training Frequency (days/week)	3.9 ± 0.9	4.4 ± 1.0	4.6 ± 0.7	4.3 ± 0.9	0.21
One-Repetition Maximum (kg)	124 ± 20.0	129 ± 22	118 ± 17	123 ± 19	0.44
Energy Intake (kcals/day)	2424 ± 482	2907 ± 501	2658 ± 1005	2655 ± 726	0.36
Carbohydrate Intake (grams/day)	247 ± 46	276 ± 62	286 ± 134	270 ± 91	0.60
Protein Intake (grams/day)	133 ± 44	214 ± 70	166 ± 68	169 ± 68	*0.03
Fat Intake (grams/day)	93 ± 30	105 ± 42	101 ± 42	99 ± 37	0.78
Relative Energy Intake (kcal/kg/day)	36.3 ± 17.9	30.6 ± 14.7	28.7 ± 15.7	31.8 ± 16.0	0.55
Relative Carbohydrate Intake (g/kg/day)	3.2 ± 0.6	3.0 ± 1.4	2.0 ± 0.6	3.1 ± 1.4	0.90
Relative Protein Intake (g/kg/day)	2.3 ± 2.0	2.4 ± 1.4	1.8 ± 1.1	2.1 ± 1.5	0.66
Relative Fat Intake (g/kg/day)	1.32 ± 0.6	1.15 ± 0.7	1.08 ± 0.6	1.18 ± 0.6	0.68

*Oneway ANOVA, $p < 0.05$.

Table 2: Training progression for all workouts, sets, reps, % 1RM over 4- week training period

Sessions	1 - 4	Prior to session 5, retest 1RM for all subjects	5 - 8
# of Sets	4		4
% 1RM	80%		85%
Repetitions	6		6
Eccentric Duration (seconds)	2, 4 or 6		2,4,or 6

Workouts 1-4 incorporated 80%1RM for all groups. Workouts 5-8 incorporated 85% 1RM for all groups. Training frequency was 2x/week with 72 hours recovery between sessions.

Table 3: 1RM, vertical jump, peak power, peak velocity, and average power values.

Variable	Group	Week 0 (pre)			Week 4 (Post)			Significance			
		Set 1	Set 2	Set 3	Set 1	Set 2	Set 3				
1 RM (kg)	2 s	124 ± 20	***	***	135 ± 23	***	***	Within	0.007	Time	< 0.001
	4 s	129 ± 22	***	***	146 ± 30	***	***	Within	<0.001	GxT	0.31
	6 s	118 ± 17	***	***	133 ± 17	***	***	Within	<0.001		
Vertical Jump (inches)	2 s	66 ± 11	***	***	69 ± 11	***	***	Within	0.02	Time	0.004
	4 s	69 ± 9	***	***	70 ± 9	***	***	Within	0.40	GxT	0.07
	6 s	61 ± 9	***	***	62 ± 9	***	***	Within	0.30		
Peak Power (w)	2 s	935 ± 184	944 ± 177	941 ± 175	1023 ± 189	1051 ± 200	1062 ± 197	Within	0.001	Time	< 0.001
	4 s	971 ± 199	1004 ± 199	1012 ± 202	1055 ± 193	1086 ± 203	1093 ± 211	Within	0.003	GxT	0.65
	6 s	861 ± 117	870 ± 123	870 ± 127	938 ± 134	957 ± 144	961 ± 151	Within	<0.001		
Peak Velocity (m/s)	2 s	1.70 ± 0.15	1.72 ± 0.13	1.72 ± 0.13	1.72 ± 0.15	1.76 ± 0.17	1.78 ± 0.17	Within	0.19	Time	0.29
	4 s	1.67 ± 0.09	1.73 ± 0.11	1.74 ± 0.09	1.64 ± 0.09	1.69 ± 0.07	1.70 ± 0.08	Within	0.29	GxT	0.04
	6 s	1.65 ± 0.15	1.67 ± 0.12	1.67 ± 0.14	1.59 ± 0.12	1.61 ± 0.14	1.62 ± 0.14	Within	0.03		
Average Power (w)	2 s	528 ± 104	532 ± 103	533 ± 103	576 ± 95	592 ± 108	595 ± 110	Within	0.001	Time	< 0.001
	4 s	568 ± 127	582 ± 123	579 ± 127	612 ± 116	629 ± 119	630 ± 126	Within	0.002	GxT	0.43
	6 s	497 ± 89	499 ± 82	498 ± 84	530 ± 94	538 ± 97	539 ± 99	Within	0.004		

Chapter 4

SUMMARY, RECOMMENDATION, AND FUTURE STUDIES

Summary

In summary, our results provide compelling evidence that varying eccentric contraction durations can be effective as a method to increase acute maximal strength and power output performance in trained college aged men who have previous weight training experience. These findings are important for the strength and conditioning professional to more fully understand that expressions of strength and power through eccentric training and altering the pattern of eccentric contractions can impact how an athlete adapts to training. Provided that increases in strength and power are the primary outcome goal, our work introduces a new paradigm that can be considered when implementing eccentric training and eccentric contraction durations into the training and therapy programs of active, athletic and clinical populations. The approach taken throughout this study was to examine the effects of eccentric contraction duration on changes in strength, power production, vertical jump and soreness, given the very limited work focused upon the specific impact of altering the contraction speed and/or duration of only part of the contraction cycle (concentric only or eccentric only). Finally, strength and conditioning professionals should also take notice that findings from the present study provide additional evidence that short-term use of eccentric training and varying durations of eccentric activity can have a significant positive impact for populations ranging from athletes desiring peak performance to clinical patients involved in physical rehabilitation.

Recommendations

Given the positive outcomes of our study on the effects of eccentric contraction duration on muscle strength and power, vertical jump, and soreness, our initial recommendation is to extend this study to a longer training period (i.e. 6-8 weeks). While our study showed acute responses to maximal strength and power output measures, long-term training studies are justified considering strength and conditioning and fitness professionals often have to develop resistance training programs to accommodate clients and athletes who may require specific approaches and training adaptations that need attention through eccentric training. Second, while our study employed the use of a visual analog scale as subjects assessed their perceived level of muscle soreness as used in a number of previous investigations, we recommend assessing blood markers of creatine kinase, myoglobin and/or lactate dehydrogenase in order to have a more accurate representation of the muscle damage invoked by different patterns of eccentric contractions. This approach will allow for a more comprehensive examination of outcomes and markers associated with performance, muscle damage with varying eccentric contraction durations. Third, although a metronome was used by trained investigators to ensure all prescribed contraction duration parameters were followed, our chosen load assignment (80-85%1RM) required load adjustments for the 4-second and 6-second groups compared to the 2-second group, as subjects faced a greater challenge trying to complete the necessary sets and reps for their prescribed eccentric duration. Specifically, many participants in the 4-second group and all participants in the 6-second group, had to have their assigned load reduced by 10% in order for all remaining repetitions and sets to be completed at the revised resistance level, and at the same contraction duration Therefore, we recommend slightly more conservative loading parameters (i.e. 65-70% 1RM), in order for study participants to be able to adhere to the prescribed contraction duration for a given training session with or without limited load adjustments.

Future Studies

Our study is the first to examine the effects of eccentric contraction duration on changes in strength, power, vertical jump and soreness. Based on our results and study cohort, we feel there are a number of future studies that deserve attention in order to provide a deeper investigation into the potential role of eccentric contraction duration activity and the associated benefits. To this point, additional well-controlled eccentric training studies on trained populations are needed to broaden the understanding of the underlying mechanism(s) and to enhance the knowledge of optimal eccentric training programs for athletes, strength and conditioning and fitness professionals, and physical therapists. The following highlights a number of future investigations that emphasize the delivery of practical recommendations for all potential applications, including the strength and conditioning field and in clinical practice.

1). Although we prioritized the use of a closed kinetic chain movement that engaged multiple joints across the lower body within a movement pattern similar to many daily life and athletic movements versus an open kinetic chain movement that has been used in previous studies, we would like to see the use of this strategy continue with a change in exercise selection. Specifically, we suggest employing the same methodology as used in the present study, with the use of a free bar bench press and free bar squat (or front squat) exercise with corresponding power production and training to assess the effects of the same measured variables. This recommendation would use an more practical exercise when compared to the squat using the Smith machine, and especially compared to the open-chain, single-joint movements previously used. Greater consideration should be made to the prescribed loading pattern and special care must be taken to ensure proper technique and safety for all involved participants.

2). Studying females who have resistance training experience is justified as this could point to previously described gender differences in the muscle’s exposure to sex steroids and differences in how males and female muscle respond to damaging exercise. Work on eccentric training with women has potential to help many athletes and active individuals. The implications may include a favorable style of training to reduce sport related injuries related to landing with closed chain kinetic positions (jump landing and ACL tears).

3). A number of eccentric training strategies (i.e. 2/1 technique, two-movement technique) exist that can allow for a wide variety of applications across nearly all populations. While recent work has highlighted many ways how eccentrics can be incorporated into the training and therapy programs of active, athletic and clinical populations (4), not a single study has examined the efficacy of any one of these techniques, either independently or in combination with other training approaches. Therefore, future studies should explore these eccentric training techniques in order to implement them into training programs, and to encourage and promote the needed scientific investigations through which these strategies can impact all populations.

4). Conditions associated with individuals following surgery (i.e. post ACL), other clinical conditions including tendiopathies, osteopenia, the aging and elderly population and those who may experience a progressive decline toward musculoskeletal and neuromuscular impairments can benefit greatly from eccentric exercise. While these conditions may result in a progressive and continual reduction in muscle strength, the incorporation of eccentric training can and is currently used as a treatment strategy for its ability to improve muscle strength and power in these populations (2, 3, 5). However, although the current consensus (1) states that exercise (particularly eccentric components) is generally recommended, there are currently no common recommendations for all individuals, and guidelines for eccentric exercise are still lacking.

5). An issue that has not been explored is the differential effects of altering the pattern of eccentric duration activity and tempos with respect to muscle hypertrophy. While a dearth of studies have examined the comparison of concentric and eccentric speeds on hypertrophic superiority, research is required to draw a firm conclusion which specific eccentric duration(s) may evoke any hypertrophic advantage.

6). The development and integration of multi-exercise eccentric guidelines are non-existent across all populations. Therefore, it is critical to examine the combined effects of utilizing upper and lower body exercise regimens with varying eccentric durations including progressive increases in percent load over time into the training and therapy programs of active, athletic and clinical populations. These guidelines serve multiple purposes and objectives, which include: a) providing information for both researchers and practitioners (i.e. strength and conditioning professionals) on specific eccentric guidelines to use for a variety of exercises; b) the load that corresponds best for each eccentric contraction duration; c) which exercises, or groups of exercises exhibit the greatest increases in strength and power outcomes and what groups of exercises best fit into the realm of physical rehabilitation; and d) based on results found, coaches, trainers, and possibly those in the clinical practice can expect to achieve a certain amount of repetitions for a specific exercise, each eccentric duration, and for each load established. These studies will provide additional scientific support for of the optimal length of an eccentric duration (i.e. 6s limit) and what load should be prescribed for varying eccentric durations for each exercise.

7). Finally, and as a direct extension of the previous recommendation, it is essential to determine (based on research studies) a similar combination of recommendations for trained, untrained, young, older and clinical populations.

References

1. Lastayo P, Marcus RL, Dibble L, Frajacomo F, and Lindstedt SL. Eccentric Exercise in Rehabilitation: Safety, Feasibility and Application. J Appl Physiol (1985), 2013.

2. Lorenz D. Eccentric Exercise Interventions for Tendinopathies. Strength and Conditioning Journal 32: 90-98, 2010.

3. Lorenz D and Reiman M. The role and implementation of eccentric training in athletic rehabilitation: tendinopathy, hamstring strains, and acl reconstruction. International journal of sports physical therapy 6: 27-44, 2011.

4. Mike J, Kerksick, CM, Kravitz, L. How to Incorporate Eccentric Training Into a Resistance Training Program. Strength and Conditioning Journal. 37 (1): 5-17. February 2015.

5. Shalabi A, Kristoffersen-Wilberg M, Svensson L, Aspelin P, and Movin T. Eccentric training of the gastrocnemius-soleus complex in chronic Achilles tendinopathy results in decreased tendon volume and intratendinous signal as evaluated by MRI. Am J Sports Med 32: 1286-1296, 2004.

Appendix A

The University of New Mexico Consent to Participate in Research

The Effects of Eccentric Contraction Duration on Muscle Strength, Power Production, Vertical Jump and Soreness.

Purpose and General Information

You are being asked to participate in a research study that is being done by Len Kravitz, PhD, who is the Principal Investigator, and co-investigator Jonathan Mike and their associates. This research is being done to evaluate The Effects of Eccentric Contraction Duration on Muscle Strength, Power Production Vertical Jump and Soreness . You are being asked to participate because you are a healthy male between the ages of 18-30 years and participate in regular resistance training. Approximately 30 people will take part in this study at the University of New Mexico.

This form will explain the study to you, including the possible risks as well as the possible benefits of participating. This is so you can make an informed choice about whether or not to participate in this study. Please read this Consent Form carefully. Ask the investigators or study staff to explain any words or information that you do not clearly understand.

What will happen if I participate?

If you agree to be in this study, you will be asked to read and sign this Consent Form. After you sign the Consent Form, the following things will happen:

Initial Study Contact and Visit:

To begin the study, you will report to the Exercise Physiology Lab in Johnson Gym on the University of New Mexico campus in the morning first to be given general information about the study. You will be asked to read and sign this combined consent and HIPAA form if you are interested in participating. In addition, you will also fill out a health history questionnaire, and a resistance training questionnaire.

Familiarization Sessions

After agreeing to participate and signing this informed consent document, you will be asked to return to the research laboratory to complete a familiarization session consisting of a vertical jump, a maximal strength test and jump squats. The purpose of this session is to allow investigators to provide necessary instructions and to allow you the opportunity to practice and become more familiar with these sessions. At least 4 days will separate your familiarization session and your baseline testing session.

Pre-Test Instructions

After completing the familiarizaiton session, you will be given a food record that will you will complete and bring back with you for your next study visit. On this form and in an extremely detailed manner, you are instructed to record all of the food and fluid you consume over three typical week days and one typical weekend day. Prior to arriving for your initial test, you will abstain from alcohol or nicotine use and refrain from participating in intense exercise for 48 hours.

Baseline Testing Procedures

Upon arriving to the research laboratory you will give your completed food record to a research team member before having your body composition measured (% body fat) using skinfold calipers at three locations (chest, abdomen and thigh). You will then have your maximal power determined using a series of jump squat movements. To conclude this testing, you will then have your maximal strength level (1RM) determined. The muscle groups performed in the squat exercise consist primarily of the hamstrings (biceps femoris, semimembranosus and semitendinosus), quadriceps (rectus femoris, vastus intermedius, vastus lateralis and vastus medialis), and gluteus maximus. All 1RM testing will begin with two sets of ten repetitions using a resistance that equates to 50% of subject's self-reported 1RM. Next, each subject will complete an additional warm-up set at 80% of self-reported 1RM. Using standard National Strength and Conditioning Association (NSCA) guidelines, the load will be increased 10-20% using one-repetition sets until only one successful repetition can be completed.

Please note, the fasting portion of the baseline strength measurements have been removed. All other procedures are appropriate and will be used

Workout #1

At least 4 days will separate your baseline testing session and your first workout. Your level of muscle soreness and will be reported as well as determining your vertical jump. All workouts will consist of four sets of six repetitions at 80-85% 1RM using the prescribed format of resistance training. Approximately 3 minutes of rest will be provided between each set of exercise. Prior to completing the first and last workout, participants will have their vertical jump height assessed using a Vertec. The Vertec assesses vertical jump height by measuring the difference between the fully extended standing reach height and the maximal vertical jump and reach height. The reach height for the Vertec will be established using a body position of an erect stance, both feet together and flat on the ground, both arms fully extended overhead, and with the head and eyes in a neutral position. The subjects will be instructed to perform the counter-movement jump (CMJ) that requires participants to begin in an upright position with the feet parallel to each other and hip to shoulder width apart. Upon a verbal cue from trained investigators, subjects will perform a rapid countermovement by flexing the knees and hips. After the subjects attain their chosen depth of descent, they will then explosively extend at the hips, knees and ankles to achieve a maximal jump height. After the initial description of the CMJ, subjects will be provided two warm-up jumps. Study participants will then complete three maximal-effort jumps with a one-minute rest period between each jump attempt. The best of three trials will be recorded.

Eccentric Training

Using a two day per week training protocol over a four week period, you will complete eight workouts consisting of four sets of six repetitions with varying durations of eccentric contractions. All workouts and repetitions will be completed using a plate-loaded Smith squat exercise and a resistance level that equates to 80 – 85% 1RM. All workouts will be separated by 72 hours meaning that some participants will follow a Monday-Thursday training protocol while others will utilize a Tuesday-Friday approach.

You will be placed into one of three training groups. The first group will be a control group and will complete all repetitions using a traditional concentric-eccentric contraction pattern (two-second concentric, one-second pause, two-second eccentric). A second group will complete all workouts using a similar contraction pattern while incorporating a four-second eccentric contraction (two-second concentric, one-second pause, four-second eccentric). The third and final group will complete all workouts using a similar contraction pattern while incorporating a six-second eccentric contraction (two- second concentric, one-second pause, six-second eccentric contraction).

No rest will be allowed between each repetition and a rest period of three minutes will be observed between completed sets. To ensure all prescribed contraction duration parameters are followed, a metronome will be used and monitored by trained investigators. In the event any study participant is unable to adhere to the prescribed contraction duration due to muscular fatigue and on a workout-by- workout basis, the weight will be reduced by 10% and all remaining repetitions will be completed at the revised resistance level and at the same contraction duration.

Final Workout

Prior to your final workout, you will again report to the research laboratory in the morning before reporting your level of muscle soreness and determining your vertical jump. Your final workout will be identical to all previously completed workouts and consist of four sets of six repetitions at 80-85% 1RM.

To again determine the extent to which different durations of eccentric contractions impact changes in vertical jump and soreness, you will report back to the laboratory 24, 48 and 72 hours after completing your final workout.

Final Testing Session

Your final testing session will consist of an identical battery of tests as was completed at the start of the study. Briefly, you will again complete a four-day food and fluid record and bring that completed form with you to the research laboratory. A minimum of 48 hours must pass between your last completed workout and your final testing session to ensure you are rested and can perform optimally. Using identical procedures, you will have your maximal strength, vertical jump and maximal power determined during this final testing session.

Upon completion of your final testing session, your participation in this study will be over. Participation in this study will take a total of 10 - 12 hours over a period of 5 weeks

What are the possible risks or discomforts of being in this study?

Every effort will be made to protect the information you give us. However, there is a small risk of loss of privacy and/or confidentiality . The risks involved with this study are more than minimal. You may feel sensations of muscular soreness from the eccentric training protocol. To mimimize your risks or discomforts during the tests, we are recruiting only those who have experience with resistance training. You will be inconvenienced by the time spent during testing. In addition, all study participants will be required to abstain from caffeine or nicotine for 12 hours prior to each testing session. You may find it hard to abstain from intense, unfamiliar physical activity and exercise for 48 - 72 hours prior to study visits. As with all research, there is a risk of loss of confidentiality and privacy. There is a small risk of minimal discomfort during the skinfold test due a mild pinch at the three sites (chest, abdomen thigh).

How will my information be kept confidential?

Your name and other identifying information will be maintained in locked files, available only to authorized members of the research team, for the duration of the study. For any information entered into a computer, the only identifier will be a unique study identification (ID) number. Your health questionnaire, informed consent, and HIPAA will be completed in a private room with the research team in order to protect your privacy. All tests will be conducted in a private room within the Exercise Physiology lab, which will allow you to feel at ease with the research protocol. Prior to each test, the research team will explain the procedures that will take place, and we will give you an opportunity to ask questions or voice concerns that you may have prior to beginning each test. The research team will not access any outside information, such as your medical records. Only the paperwork for the current study will be accessed. The paperwork that includes subject identifiers

(HIPAA form, consent) will be stored separately from de-identified data and forms. The key-matching subjects with subject numbers will be stored in a separate file only available to the PI. All paperwork will be stored in locked filing cabinets. Any personal identifying information and any record linking that information to study ID numbers will be destroyed when the study is completed. Information resulting from this study will be used for research purposes and may be published; however, you will not be identified by name in any publications.

Information from your participation in this study may be reviewed by federal and state regulatory agencies, and by the UNM Institutional Review Board (IRB) which provides regulatory and ethical oversight of human research. There may be times when we are required by law to share your information. However, your name will not be used in any published reports about this study.

What are the benefits to being in this study?
There may or may not be direct benefit to you from being in this study. However, your participation may help find out how the resistance training study impacts your ability to elicit progress in muscular strength outcomes. Following completion of the study the subject will be informed of their results from the trials. Any result from this study could be used for possible resistance training programs, if that is of interest to the subject.

What other choices do I have if I don't participate?
Taking part in this study is voluntary so you can choose not to participate.

Will I be paid for taking part in this study?
You will be compensated no more than $50 for the time you invest in this study and you will receive payment upon completion of the study in the form of a gift card. You will be compensated $25 for completion of the first testing session, $5 for each week of training completed and $30 for completing the final testing session.

What will happen if I am injured or become sick because I took part in this study?
If you are injured or become sick as a result of this study, UNMHSC will provide you with emergency treatment, at your cost.

No commitment is made by the University of New Mexico Health Sciences Center (UNMHSC) to provide free medical care or money for injuries to participants in this study.

In the event that you have an injury or illness that is caused by your participation in this study, reimbursement for all related costs of care will be sought from your insurer, managed care plan, or other benefits program. If you do not have insurance, you may be responsible for these costs. You will also be responsible for any associated co-payments or deductibles required by your insurance.

It is important for you to tell the investigator immediately if you have been injured or become sick because of taking part in this study. If you have any questions about these issues, or believe that you have been treated carelessly in the study, please contact the Institutional Review Board (IRB) at (505) 272- 1129 for more information.

How will I know if you learn something new that may change my mind about participating?
You will be informed of any significant new findings that become available during the course of the study, such as changes in the risks or benefits resulting from participating in the research or new alternatives to participation that might change your mind about participating.

Can I stop being in the study once I begin?
Yes. You can withdraw from this study at any time without affecting your access to care, education, etc.

The investigators have the right to end your participation in this study if they determine that you no longer qualify to take part, if you do not follow study procedures, or if it is in your best interest or the study's best interest to stop your participation. The investigators may also end your participation without your consent if there is an adverse response or event to the protocol being administered or if it is discovered that you are unwilling or unable to follow the pre-testing guidelines.

As part of this study, we will be collecting health information about you. This information will not be shared with anyone other than the study team. This information is "protected" because it is identifiable or "linked" to you.

Protected Health Information (PHI)
By signing this Consent Document, you are allowing the investigators and other authorized personnel to use your protected health information for the purposes of this study. This information may include: height, weight, % body fat, 1RM testing, vertical jump, soreness, dietary log information. Should you not qualify for the study, all information collected will be destroyed.

In addition to researchers and staff at UNM and other groups listed in this form, there is a chance that your health information may be shared (re-disclosed) outside of the research study and no longer be protected by federal privacy laws. Examples of this include disclosures for law enforcement, judicial proceeding, health oversight activities and public health measures.

Right to Withdraw Your Authorization
Your authorization for the use and disclosure of your health information for this study shall not expire unless you cancel this authorization. Your health information will be use as long as it is needed for this study. However, you may withdraw your authorization at any time provided you notify the UNM investigators in writing. To do this, please send letter notifying the study investigators of your withdrawal to:

Len Kravitz, PhD MSC 04 2610
1 University of New Mexico Albuquerque New Mexico 87131

Please be aware that the research team will not be required to destroy or retrieve any of your health information that has already been used or shared before your withdrawal is received.

Refusal to Sign
If you choose not to sign this consent form and authorization for the use of your PHI, you will not be allowed to take part in the research study.

What if I have questions or complaints about this study?
If you have any questions, concerns or complaints at any time about the research study, Len Kravitz, PhD , or his associates will be glad to answer them at 505-277-4136 Mondays-Fridays from 8:00 a.m. to 5:00 p.m. by phone. If you would like to speak with someone other than the research team, you may call the UNM IRB office at (505) 272-1129. The IRB is a group of people from UNM and the community who provide independent oversight of safety and ethical issues related to research involving human participants

What are my rights as a research participant?

If you have questions regarding your rights as a research participant, you may call the Human Research Protections Office (HRPO) at (505) 272-1129 or visit the HRPO website at http://hsc.unm.edu/som/research/hrrc/.

Consent and Authorization
You are making a decision whether to participate in this study. Your signature below indicates that you read the information provided (or the information was read to you). By signing this Consent Form, you are not waiving any of your legal rights as a research participant.

I have had an opportunity to ask questions and all questions have been answered to my satisfaction. By signing this Consent Form, I agree to participate in this study and give permission for my health information to be used or disclosed as described in this Consent Form. A copy of this Consent Form will be provided to me.

Name of Adult Participant (print)   Signature of Adult Participant

___

Date___________________

I have explained the research to the participant and answered all of his/her questions. I believe that he/she understands the information in this consent form and freely consents to participate.

Name of Research Team Member

___

Signature of Research Team Member   Date________________

___

Appendix B

UNIVERSITY OF NEW MEXICO HEALTH SCIENCES CENTER
HIPAA[1] AUTHORIZATION TO USE AND DISCLOSE
PROTECTED HEALTH INFORMATION FOR RESEARCH PURPOSES

Title of Study: *The Effects of Eccentric Contraction Duration on Muscle Strength, Power Production Vertical Jump, and Soreness*

Principal Investigator: **Len Kravitz, PhD**
UNMHSC Department: **Health, Exercise & Sport Sciences**
Mailing Address: **lkravitz@unm.edu**
Co-Investigators: **Jonathan Mike, Nathan Cole, Chris Hererra, Trisha Ann VanDusseldorp,**

Sponsor: **N/A**

1. **What is the purpose of this form?** You have been asked to take part in a research study. The consent form for this study describes your participation, and that information still applies. This extra form is required by the federal Health Insurance Portability and Accountability Act (HIPAA). The purpose of this form is to get your permission (authorization) to use health information about you that is created by or used in connection with this research.

2. **What if I don't want my personal health information (PHI) to be used in this research study?** You do not have to give this permission. Your decision not to sign this form will not change your ability to get health care outside of this research study. However, if you do not sign, then you will not be allowed to participate in the study.

3. **What PHI am I allowing to be used for this research?** The information that may be used includes: Food and beverage log, estimation of %body fat, height, weight, 1RM testing, power production, perceived soreness, and vertical jump. This information may be used to examine different durations of eccentric contractions to determine the changes in strength, rate of force production, power and muscle damage.
4. **Where will researchers go to find my PHI?** We may ask to see your personal information in records at hospitals, clinics or doctor's offices where you may have received care in the past, including but not limited to facilities in the UNM health care system.

5. **Who will be allowed to use my information for this research and why?** The researchers named above and their staff will be allowed to see and use your health information for this research study. It may be used to check on your progress during the study, or analyze it along with information from other study participants. Sometimes research information is shared with collaborators or other institutions. Your records may also be reviewed by representatives of the research sponsor or funding agency, the Food and Drug Administration (FDA) to check for quality, safety or effectiveness, or the Human Research Review Committee (HRRC) for the purposes of oversight and subject safety and compliance with human research regulations.

[1] HIPAA is the Health Insurance Portability and Accountability Act of 1996, a federal law related to privacy of health information.

6. **Will my information be used in any other way?** Your information used under this permission may be subject to re-disclosure outside of the research study and be no longer protected under certain circumstances such as required reporting of abuse or neglect, required reporting for law enforcement purposes, and for health oversight activities and public health purposes.

7. **What if I change my mind after I give this permission?** You can change your mind and withdraw this permission at any time by sending a written notice to the Principal Investigator at the mailing address listed at the top of this form to inform the researcher of your decision. If you withdraw this permission, the researcher may only use and share your information that has already been collected for this study. No additional health information about you will be collected by or given to the researcher for the purposes of this study.

8. **What are the privacy protections for my PHI used in this research study?** HIPAA regulations apply to personal health information in the records of health care providers and other groups that share such information. There are some differences in how these regulations apply to research, as opposed to regular health care. One difference is that you may not be able to look at your own records that relate to this research study. These records may include your medical record, which you may not be able to look at until the study is over. The HIPAA privacy protections may no longer apply once your PHI has been shared with others who may be involved in this research.

9. **How long does this permission allow my PHI to be used?** If you decide to be in this research study, your permission to access and use your health information in this study may not expire, unless you revoke or cancel it. Otherwise, we will use your information as long as it is needed for the duration of the study.

I am the research participant or the personal representative authorized to act on behalf of the participant. By signing this form, I am giving permission for my personal health information to be used in research as described above. I will be given a copy of this authorization form after I have signed it.

____

Name of Research Subject

____

Signature of Subject/Legal Representative   Date

____

Describe authority of legal representative

____

Name of Person Obtaining Authorization   Signature   Date

Appendix C

HEALTH HISTORY QUESTIONNAIRE

Name______________________________ Date___/___/___ Phone (H)_________________________

Date of Birth ___/___/___ Age____ Gender____ Ethnicity_______ Phone (W)__________________

Address (home)____zip__________

UNM faculty/staff___ UH staff___ UNM student___ Community___ Other______

UNM Dept/Bldg._____________________________ email______________________________________

Primary health care provider and health insurance____
(Only for information/emergency contact)
How did you hear of our services?____

♦♦

MEDICAL HISTORY

Self-reported: Height______ Weight______
Physical injuries:____
Limitations____
Have you ever had any of the following cardiovascular problems? Please check all that apply.

Heart attack/Myocardial Infarction____
Heart surgery____
Valve problems_____
Chest pain or pressure ____
Swollen ankles____
Dizziness_____
Arrhythmias/Palpitations____
Heart murmur____
Shortness of breath_____
Congestive heart failure____

Have you ever had any of the following? Please check all that apply.
Hepatitis/HIV_____
Depression_____
Cancer (specify type)__________
Rheumatic fever_____
High blood pressure_____
Thyroid problems_____
Kidney/liver disease_____
Obesity_____
Total cholesterol >200 mg/dl_____
Diabetes (specify type)_____
Asthma_____
HDL cholesterol <35 mg/dl_____
Emphysema_____
Stroke_____
LDL cholesterol >135 mg/dl_____

Trygylcerides>150 mg/dl_____

Do immediate blood relatives (biological parents & siblings **only**) have any of the conditions listed above? If yes, list the problem, and family member age at diagnosis.

____

Is your mother living? Y N Age at death______ Cause___________________

Is your father living? Y N Age at death______ Cause___________________

Do you currently have any condition not listed that may influence test results? Y N

Details____

____

Indicate level of your overall health. Excellent ____ Good ____ Fair ____ Poor_____

Are you taking any medications, vitamins or dietary supplements now? Y N

If yes, what are they?____

Do you have allergies to any medications? If yes, what are they? ________________________________

Are you allergic to latex? Y N

Have you been seen by a health care provider in the past year? Y N

If yes, elaborate ____

Have you had a prior treadmill test? Y N. If yes, when?______________ What were the results?

____

Have you ever experienced any adverse effects during or after exercise (fainting, vomiting, shock, palpitations, hyperventilation)? Y N If yes, elaborate.____

____

♦♦

LIFESTYLE FACTORS

Do you now or have you ever used tobacco? Y N If yes: type ________________

How long?______ Quantity____/day Years since quitting_______________

How often do you drink the following?

Caffeinated coffee, tea, or soda _______oz/day Hard liquor _______oz/wk Wine _______oz/week

Beer _______oz/wk

Indicate your current level of emotional stress. High____ Moderate ____ Low____

♦♦♦

PHYSICAL ACTIVITY/EXERCISE

Physical Activity

Minutes/Day (*Weekdays*) Minutes/Day (*Weekends*)

______/______ average ______/_____ average

Do you train in any activity (eg. jogging, cycling, swimming, weight-lifting)? Y N

How well trained are you?____

Vigorous Exercise (>30 Minute sessions)

_________Minutes/hours a week

♦♦

WOMEN ONLY

Please check the response that most closely describes your menstrual status:

_____ Post-menopausal (surgical or absence of normal menstrual periods for 12 months)

_____ Eumenorrheic – Normal menstrual periods (~every 28 days)

_____ Amenorrheic – Absence of normal menstrual periods for at least 3 months

_____ Oligomenorrheic – Irregular menstrual periods with occasional missed cycles.

Appendix D

Data Collection Form

Workouts 1-4

Eccentric Contraction Duration 4x6 @80% 2,4,6sec

Eccentric Contraction (2, 4, or 6 sec)	Total Load (body wt + kg) 80%1RM	Sets	Reps
		4	6
		4	6
		4	6
		4	6

Workouts 5-8
Eccentric Contraction Duration 4x6 @ 85% 1 RM

Eccentric Contraction (2, 4, or 6 sec)	Total Load (body wt + kg) 85%1RM	Sets	Reps
		4	6
		4	6
		4	6
		4	6

Appendix E

Resistance Training Questionnaire

Title of Study: *The Effects of Eccentric Contraction Duration on Muscle Strength, Power Production, Vertical Jump, and Soreness*

1**) Do you currently participate in some form of resistance training? Please circle**

Yes No

2) If you answered YES to #1, how long have you been consistently completing some form of resistance training? Consistently is defined as not allowing more than two weeks between bouts of resistance training.

6 months 1 year 2 years 3 years

3 or more years

3) Have you or are you currently utilizing some variation of a squat or leg press exercise? Examples would be leg press, back squat, front squat, hack squat, lunges, etc. This does NOT include leg extension, leg curl or calf raises.

Yes No

4) How many days per week do you resistance train?

2 days 3 days 4 days 5 or more days

5) On a scale of 0 – 10 how intense (or difficult) are your resistance training workouts? A zero means your resistance training workouts are low intensity, a rating of a 5 is moderate intensity and a rating of 10 is very high intensity

0 2 4 6 8 10

Appendix F

University of New Mexico

Effects of Eccentric Contraction Duration on Muscle Strength, Power Production, Vertical Jump, and Soreness

Perceived Muscle Soreness Rating

<u>Directions</u>:

Please indicate your perceived level of muscle soreness/overall severity of soreness in your lower body muscles and legs from the eccentric contraction from doing the squat exercise. Also consider your ability to sit and stand and any normal daily activities this might effect. Draw an intersecting line across the continuum line extending from 0-10. This mark will indicate your level of soreness (0 = no soreness, 10 = extreme soreness). The distance of each mark will be measured from zero and the measurement utilized as the perceived soreness level.

Testing Session: ______________________ Date: ___________________

0 2 4 6 8 10

Appendix G

Four-Day Dietary Log

Name:____

Directions for 4-Day Dietary Recall (three week days, one weekend day).

To determine the amount of calories you consume, please record everything you have eaten over a four-day period (three week days, one weekend day).

1. Begin the food journal with documenting the time that you ate.

2. In the column labeled "Type of Food", record what you ate. This includes any snack items or unconscious eating such as accepting a piece of candy from a friend. Please be specific in describing the food. For example, rather than writing down milk, please indicate whether it was whole, skim, 1%, 2% or chocolate; or if you consumed bread, whether it was whole wheat, white, rye, etc. If necessary, break food items down into its component parts. For instance, if you ate a turkey sandwich, write down wheat bread, turkey breast, American cheese, mustard, and lettuce. Also, include foods such as mayonnaise, salad dressing, butter, sugar, or salt. Remember to record beverages such as water, alcohol, coffee, soda, tea, and fruit juices.

3. In the column labeled "Amount", write the quantity of each food consumed. If you do not have access to measuring utensils, (measuring cups/spoons, food scale) there are examples of how to measure food on the back of the last sheet in this packet. Your results will only be as accurate as your measurements.

4. In the column labeled "Method of Preparation", document how the food was cooked (e.g., frying, braising, grilling, microwaving, steamed, etc.). Please indicate in this column the name of the restaurant if you ate out.

5. In the last two columns write down how hungry you were prior to eating (0 = not hungry to 5 = extremely hungry) and how full you were at the end of eating (0 = not full to 5 = extremely full). See sample day provided below.

Example

Date: 5/31/06

TIME	TYPE OF FOOD	AMOUNT	WHERE	METHOD OF PREPARATIO N	HUNGER 0-5	FULLNESS 0-5
7:30am Noon 3:00pm 6:00pm	Corn Flakes Milk – 2% Banana Turkey Bread, Whole Wheat Mayonnaise Tomato Green Apple Pepsi, can Medium Blizzard Chicken Breast Green Beans Rice, White Pie, Apple Coffee	¾ cup ½ cup ½ 2 oz 2 slices 1 tsp. 2 slices 1 large 12 oz. Medium 3 oz. ½ cup 1 cup 1/5 pie 2 cups	Kitchen “ “ Student Center Cafeteria “ “ “ “ Dairy Queen Home “ “ “ “	Baked Grilled, no skin Steamed, fresh Boiled		

The result of your 4-day is only as accurate as your measurements.
Please make sure the AMOUNT of each item is specific.

Day

Date:_____/____/____

TIME	TYPE OF FOOD	AMOUNT	WHERE	METHOD OF PREPARATION	HUNGER 0-5	FULLNESS 0-5

Is this a typical day? Yes No.

The result of your 4-day is only as accurate as your measurements.
Please make sure the AMOUNT of each item is specific.

Day

Date:_____/____/____

TIME	TYPE OF FOOD	AMOUNT	WHERE	METHOD OF PREPARATION	HUNGER 0-5	FULLNESS 0-5

Is this a typical day? ☐ Yes ☐ No.

The result of your 4-day is only as accurate as your measurements.
Please make sure the AMOUNT of each item is specific.

Day

Date:_____/____/____

TIME	TYPE OF FOOD	AMOUNT	WHERE	METHOD OF PREPARATION	HUNGER 0-5	FULLNESS 0-5

Is this a typical day? - - Yes - - No.

The result of your 4-day is only as accurate as your measurements.
Please make sure the AMOUNT of each item is specific.

Day

Date:_____/____/____						
TIME	**TYPE OF FOOD**	**AMOUNT**	**WHERE**	**METHOD OF PREPARATION**	**HUNGER 0-5**	**FULLNESS 0-5**

Is this a typical day? -- Yes -- No.

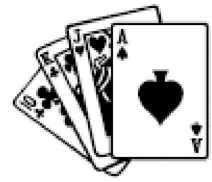
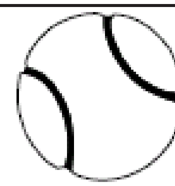
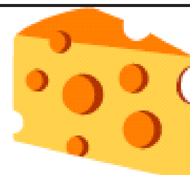
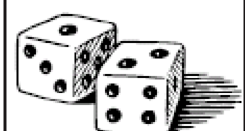
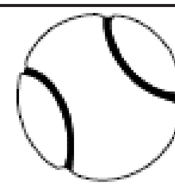
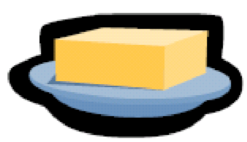
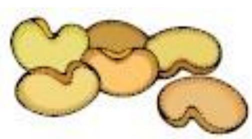
The result of your 4-day is only as accurate as your measurements.
Please make sure the AMOUNT of each item is specific.

Day

Seven Ways to Size Up Your Servings

Measure food portions so you know exactly how much food you're eating.
When a food scale or measuring cups aren't handy you can still estimate your portion.

Remember

1	3 ounces of meat is about the size and thickness of a deck of playing cards or an audiotape cassette.		=	
2	A medium apple or peach is about the size of a tennis ball.		=	
3	1 ounce of cheese is about the size of 4 stacked dice.		=	
4	½ cup of ice cream is about the size of a racquetball or tennis ball.		=	
5	1 cup of mashed potatoes or broccoli is about the size of your fist.		=	
6	1 teaspoon of butter or peanut butter is about the size of the tip of your thumb.		=	
7	1 ounce of nuts or small candies equals one handful.		=	
Standard Residence Hall Serving Sizes				

Is this a typical day? -- Yes -- No.

The result of your 4-day is only as accurate as your measurements.
Please make sure the AMOUNT of each item is specific.

Day

Chili, soups, stews	1 cup	Pasta dishes	1 cup
Rice, noodles, cooked cereal	½ cup	Meat	3-4 ounces
Egg, tuna salad	1/3 cup	Potatoes (mashed, au gratin)	¾ cup
Vegetables	½ cup	French fries	15 fries
Macaroni and cheese	¾	Scrambled eggs	2 eggs
Pancakes	cup2		

Is this a typical day? -- Yes -- No.

The result of your 4-day is only as accurate as your measurements.
Please make sure the AMOUNT of each item is specific.

Day

Is this a typical day? -- Yes -- No.

The result of your 4-day is only as accurate as your measurements.
Please make sure the AMOUNT of each item is specific.

Day

Is this a typical day? -- Yes -- No.