THE EFFECTS OF ECCENTRIC PHASE DURATION ON CONCENTRIC OUTCOMES IN THE SQUAT AND BENCH PRESS

by

Joseph P. Carzoli

A Thesis Submitted to the Faculty of

The College of Education

In Partial Fulfillment of the Requirements for the Degree of

Master of Science

Florida Atlantic University

Boca Raton, FL

August 2018

THE EFFECTS OF ECCENTRIC PHASE DURATION ON CONCENTRIC

OUTCOMES IN THE SQUAT AND BENCH PRESS

by

Joseph P. Carzoli

This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Michael C. Zourdos, Department of Exercise Science and Health Promotion, and has been approved by the members of his supervisory committee. It was submitted to the faculty of the College of Education and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

SUPERVISORY COMMITTEE:

Michael C. Zourdos, Ph.D.
Thesis Advisor

Andy Khamoui, Ph.D.

Eric Helms, Ph.D.

Michael Whitehurst, Ed.D.

Michael Whitehurst, Ed.D.
Chair, Department of Exercise Science and Health Promotion

Valerie J. Bristor, Ph.D.
Dean, College of Education

Khaled Sobhan, Ph.D.
Interim Dean, Graduate College

June 28, 2018
Date

ACKNOWLEDGEMENTS

The author wishes to express sincere gratitude to those individuals who were vital to the completion of this project.

I easily have the coolest supervisory committee of all time, and I would like to start by thanking its leader and my advisor, Dr. Zourdos, for being the single greatest influence on my development as a scientist thus far. What I have learned from you has been nothing short of invaluable – from introducing me to the glory of Metallica, sound monetary policy, and the principles of personal liberty when I was a senior in high school, to helping me develop my undergraduate thesis while at Florida State, all the way to the endless guidance you have provided since my arrival at FAU. I am forever grateful for the time and effort you have spent mentoring me these past two years and will always remember how important googling something is before asking for help. I sincerely apologize for anytime I jammed you up by being a remarkably better athlete at all the sports we played in the muscle lab. You competed well, but still earned a championship grade of D+, but at least that's a grade they don't hand out too often. While I wish my thesis could have had a stronger focus on developments in personal liberty, I am still very grateful that you allowed me to research exactly what I wanted to. Your endless support of your students pursuing research and careers that genuinely interest them is one of the biggest reflections of your integrity and values as a mentor. I look forward to all of our collaborative work in the future but that is far outweighed by my excitement for the development of our friendship.

To Dr. Whitehurst, who is unquestionably the most awesome department chair ever, thank you for always taking the time to get to know me. My respect for you increases with every conversation we have, whether it is about science or life, and your open-door policy has been a perfect catalyst for those very talks. Although we were unable to start the creatine supplementation and Alzheimer's Disease study I was initially considering for my thesis, decisively changing your mind on the merit of such research is one of my proudest academic achievements thus far. This department is making remarkable moves in its production of research and student development, both resulting from the culture you have fostered as department chair. Thank you for everything you have done for this program and for my development as a scientist. I look forward to your visits in Colorado and want to be just like you when I grow up.

To Dr. Khamoui, fellow FSU alum who started at FAU exactly when I did, thank you for your help in revising my thesis. Your easy-going, yet productive approach to my thesis helped make this as stress-free as I could have hoped. Outside of this project, I am very grateful for the opportunity to help with and learn from your animal research despite lacking basic biochemistry lab skills. That has been an invaluable experience during my Master's that I hope to expand on in my future research. Also, I agree – Ichiyami is absolutely delicious.

To Dr. Helms, the online muscle guy, thank you for being part of my committee despite living in another country. Your recommendation to use Kinovea for video analysis will be a tremendous benefit as we prepare the manuscript of this thesis for publication. I am glad data collection for your dissertation began at FAU the same semester I started the Master's program. That provided the perfect opportunity for me to jump into research in the Muscle Lab, become more familiar with resistance-training research, and get to know you better. I am greatly looking forward to working together in the future and hope your calves are bigger than ever before.

Next, I would like to acknowledge the Muscle Lab team and my colleagues in the Master's program. To start, I have to thank Colby Sousa, who was unquestionably the MVP for my data collection. Colby, you are the man. I could not have completed my thesis without your help. You were there for every session and ensured I didn't lose my mind listening to a metronome for 5 weeks straight. My favorite memories in the Muscle Lab will be of us inventing sports and winning championships. Whether it was Stickball, Soc^2, Super Soc^2 (Soc^4), 4 Square, 4 guys 2 balls, or Bop-It, you will always be the #1 draft pick. Your work ethic, outgoing personality, and positive approach to everything you do will lead you to accomplish great things. I'm really excited you are starting your PhD in New Zealand working with Dr. Helms and can't wait to see the work you two produce together. Our paths shall cross again and I know I can always count on you to "start the fun up." I hope to join you as a member of NASA some day.

To Becky Cerminaro and Alissa Babain, thank you both so much for helping with data collection as undergraduate students. Your endless dabs behind my back and supply of food in the lab made every day a fun day (even though we all know Colby brought in all the food). While we joked around and often threw things at each other in the Muscle Lab, we got our work done and did it well. Both of you were great contributors to the culture we had in the lab and my thesis could not have been completed without your help. I know you both will be successful in your respective careers and wish you the best with your future schooling.

To Dan Belcher, Trevor Johnson, and RJ Pratt, thank you all for helping with pilot testing and data collection. Dan, although your hand was broken and you were severely limited helping with data collection, your assistance during pilot testing and with creating the study design were paramount to my thesis starting. Your consistent, pessimistic outlook on just about everything really kept me grounded these past two years and I know you will do big things at Penn State. Trevor, thank you for being a pilot subject and for helping with data collection. I am really excited to see you step outside of your comfort zone and dive headfirst into you current research interests. You were the best team player this year having helped out with all 5 thesis projects that were completed. I know you will be successful with whatever you apply yourself to. RJ, thank you for helping with data collection. I could always rely on your help when we were short-staffed in the lab and truly appreciate the time you committed to my project. I wish you the best with your future endeavors.

To Gabriel Peña and Jessica Halle, thank you both for helping with data collection at the times I needed it most. You both were there for me on a moment's notice and assisted with the most remedial, yet necessary tasks. Gabe, it is an honor to call you a colleague and a friend. You are one of the most reliable and considerate friends I've ever known. I believe everyone in the Master's program respected you as the unspoken leader of our graduating class. Your contagious work ethic helped our class create one of the most productive research years this program has ever seen. I was flattered when you allowed me to help with your thesis and glad we were working with mice instead of a loose seal. Jess, despite your unfailing quest to make every interaction between us awkward, I have a tremendous amount of respect for you. I know you will be successful in whatever you commit to and am excited to see where your future leads.

Next, I would like to thank other current or past FAU students who allowed me to help with and learn from their theses or who's company I just enjoyed. Mike Haischer and Dan Cooke, thank you both for allowing me to help with your data collection. I wish you both the best in your PhD's. Jared Perlmutter, thank you for being my first friend when I moved to South Florida. I wish you the best with whatever career you commit to and hope your sports teams always do mildly well. Peter Ferrandi, thank you for always making everything weird. I enjoyed all of our philosophical discussions (including the outrageous jokes that accompanied them) and greatly respect your approach to asking some of the most difficult questions. I hope our future encounters are insightful and ridiculous. Chad Dolan, though our time as students did not overlap at FAU, I am really glad we got to know each other over the past year. You are one of the most respectful people I’ve ever met and I truly appreciate your help with pilot testing and study design for my thesis. Hector Paez, thank you for being such a good friend and a defender of liberty. I know you will do great things during in your PhD program and hope you always consider what else can be done with scarce resources that have alternative uses.

No FAU Exercise Science Thesis would be complete without acknowledging the two ladies that keep this place running. Peggy Donnelly and Denise Merrill, thank you both so much for being the nicest people imaginable. Every day I walk into the front office and get the chance to catch up with you guys is a great day. You never failed to make me smile and are instrumental to the success of every student that comes through this program.

Next, I would like to thank the individuals responsible for helping me first get involved in research at FSU. Dr. Ormsbee, Dr. Panton, and soon-to-be-Dr. Alex Klemp, thank you all for taking the risk and helping me complete my undergraduate thesis. Without that project going as well as it did, I would not be pursuing a career in academia. I am very grateful of your guidance during my undergraduate campaign and hope our paths cross again soon.

Finally, I would like to thank my family, without whom I would be nothing. Pops, I am so proud to call you my dad. You have been a perfect role model, provided sound advice when I needed it most, and always helped me to remember not to sweat the small stuff. I only hope I can imitate your work ethic, love for others, and excellence in everything you commit to. My greatest aspiration is to be the type of father to my children that you are to me. Mom, I could not have achieved anything that I have without your love and support. You always taught me to do the right thing and I would not be the man that I am without you being the perfect mother that you are. Your faith is inspiring and I am so grateful God blessed me with you as my mom. Trish and Jessie, thank you both for being amazing sisters and encouraging me in every goal I set. Coop, I am so happy you joined our family over 10 years ago and that I can call you my brother. Thank you for unconditionally supporting me in my career path. Ty, words cannot describe how proud I am that you're my brother. Along with dad, you have been a phenomenal role model and helped shape me into the man that I am. As you've said before, there are people who would kill to have the type of relationship we have. I credit that to your unparalleled capabilities to lead-by-example, educate yourself, and think critically, all of which I admire greatly. You may not be as wise as an owl, but you'll always be a hoot to me. Finally, to my wife, Alisha, thank you for loving and supporting me in every way possible. From high school, to undergrad, to my current Master's degree and to my eventual PhD schooling, your encouragement throughout my academic career has made all the difference in my success. Marrying you will forever be my greatest achievement because it is the foundation that every future accomplishment I have will be built on. I love you more than you could ever know and I thank God for you every day. I do not know why God blessed me with such an amazing family, but I love you all dearly and am forever grateful for your support.

"Out of the fullness of his grace he has blessed us all giving us one blessing after another." – John 1:16

ABSTRACT

Author: Joseph P. Carzoli

Title: The Effects of Eccentric Phase Duration on Concentric Outcomes in the Squat and Bench Press

Institution: Florida Atlantic University

Thesis Advisor: Dr. Michael C. Zourdos

Degree: Master of Science

Year: 2018

The purpose of this research was to investigate the effects of eccentric phase duration on concentric outcomes at 60% and 80% of one-repetition maximum (1RM) in the squat and bench press. Sixteen resistance-trained males completed four laboratory visits as follows: Day 1- 1RM testing; Day 2- establishment of normative eccentric durations; Days 3 and 4- randomized fast (0.75 times) or slow (2 times) eccentric duration variations, which were controlled by visual and auditory metronomes. Eccentric duration was significantly and inversely correlated with average concentric velocity (ACV) at 60% (r = 0.408) and 80% (r = -0.477) of 1RM squat and at 100% of 1RM bench press. At 60% of 1RM squat, both fast and slow eccentric conditions produced greater ($p<0.001$) peak concentric velocity (PCV) than normative duration with fast also producing greater PCV than slow ($p=0.044$). Therefore, fast eccentric durations may benefit concentric velocity.

THE EFFECTS OF ECCENTRIC PHASE DURATION ON CONCENTRIC OUTCOMES IN THE SQUAT AND BENCH PRESS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Athletic performance is determined by both concentric (muscle shortening) and eccentric (muscle lengthening) phases of muscle contraction. In resistance training, the eccentric phase precedes the concentric phase in most movements. Therefore, concentric performance in resistance training is the beneficiary of the stretch shortening cycle (SSC), or the contraction of a muscle in response to a stretch (2). Specifically, the SSC stipulates that muscle lengthening during the eccentric portion of an exercise results in increased force of muscular shortening during the concentric phase (4).

Importantly, the degree to which concentric performance benefits from the SSC is determined by the magnitude and velocity of the eccentric phase. Specifically, Meylan et al. (2010) observed that faster and larger amplitude counter-movements (i.e. eccentrics) for bodyweight jump exercises improved concentric performance to a greater degree than slower counter-movements (32). These findings from Meylan et al. demonstrate that the benefits of the SSC are velocity-dependent, in that the faster the eccentric the greater the concentric performance

However, there may be limitations to this principle, as Granata and England (2006) observed that faster trunk movement velocity led to altered body control and changes in spinal alignment (19), possibly demonstrating a point of diminishing returns for eccentric velocity benefits. Additionally, movement velocity has been shown to affect torso muscle recruitment and co-contraction, resulting in increased spinal load during fast paced lifting movements (20). Further, faster movement speed also increases tendon strain and subsequently decreases muscle strain (16). Taken together, these findings demonstrate that even though a fast eccentric can lead to improved concentric performance there is not only a point of diminishing returns, but an increased risk of injury. To counter, athletes may perform lifts at slower velocities, but this results in greater fatigue from increased time under tension and decreased power output (40,46). Therefore, when performing a compound resistance training movement, such as the back squat, it seems that optimizing eccentric velocity is a balance between moving fast enough to maximize the SSC and limit fatigue, while also controlling the movement to avoid injury (i.e. changes in spinal alignment). Ultimately, elucidating the appropriate eccentric duration in relation to velocity is necessary to optimize performance and reduce injury in major compound resistance exercises. However, to our knowledge, there is no study that has examined the effects of various individualized eccentric durations on concentric performance in compound resistance training exercises.

Therefore, the purpose of this study was to analyze how manipulating the eccentric duration of a back squat and bench press to 0.75 times (fast) and two times (slow) an individual's normal eccentric duration influences concentric performance (velocity, barbell path, and rating of perceived exertion-RPE) compared to a normative duration at 60 and 80% of one-repetition maximum (1RM). It was hypothesized that faster eccentric durations would result in faster average (ACV) and peak concentric velocity (PCV) and lower RPE values, yet worse bar path and increased ROM than both a normative and slow eccentric duration. Further, we hypothesized that slow durations would result in the opposite concentric outcomes of the first hypothesis than the fast and normative eccentric conditions.

II. REVIEW OF LITERATURE

Velocity Based Resistance-Training

Eccentric and Concentric Velocity

The velocity at which eccentric and concentric muscle contractions are performed greatly influence resistance training performance and adaptations (3,30). As a result, it has become desirable to accurately measure free-weight lifting velocity to optimize athletic performance. The best way to achieve this is with linear position transducers, which often bear a large financial burden that limits their use to academic and professional sport settings. Recently, a relatively inexpensive and accurate linear position transducer in the Open Barbell System (Squats and Science, Brooklyn, USA) was created, further spreading the ability to measure lifting velocity to strength training specialists and individuals involved in resistance training.

Measuring the load and velocity of resistance training movements has established a clear relationship between the two. Specifically, the velocity of concentric muscle contractions decrease with increasing load and force output (18,24,27,41), allowing practitioners to use one variable to accurately estimate the other (17). This was demonstrated when Gonzalez-Badillo and Sanchez-Medina (2010) observed that the mean velocity attained with a given absolute load in the bench press can be used to effectively estimate the relative load (i.e. %1RM) that load represents (18). Following this, Zourdos et al. (2016) observed a strong inverse relationship between ACV and RPE at all relative loads in both experienced and novice lifters in the back squat while

Ormsbee et al. (2017) observed the same relationship in the bench press (35,50). Additionally, Helms et al. (2016) demonstrated that ACV has a strong inverse correlation with both RPE and %1RM in the squat, bench press and deadlift in experienced powerlifters (24). Despite Helms et al. (2016) showing RPE to be an accurate measure of intensity, the objectivity of velocity likely makes it a better measure of intensity (18).

Concentric movement velocity for free-weight barbell lifts can be measured via ACV and PCV (18,41). More specifically, ACV has been proposed as the most appropriate velocity measure for non-ballistic exercise (i.e. back squat) as it likely best represents an athlete's ability to move a load through the entire concentric portion of a lift. Resultantly, PCV has been proposed as the best measure for ballistic exercise (i.e. squat jumps) as it represents the acceleration required to perform these movements (10,27).

While there is a plethora of data analyzing concentric muscle contraction velocity in resistance training, there is scarce data on eccentric velocity. Acutely, repetitions with longer eccentric duration increase muscle activation more than repetitions with shorter eccentric durations even when concentric duration is the same (31). Still, it remains unclear what specific eccentric velocities result in the best concentric phase outcomes for resistance-training exercises.

Much of the research assessing the relationship between controlled eccentric and concentric muscle contraction durations have looked at their effects on training adaptations (15), muscle damage (8), markers of muscle hypertrophy (39), and muscle conduction velocity (37), often performed using an isokinetic dynamometer such as a Biodex (Biodex Medical Systems, N.Y., USA). This machine directly controls the eccentric and concentric phase durations of a movement, making it highly effective for analyzing muscle contraction velocities. Unfortunately, findings on such a control-capable device do not always translate to free-weight resistance training outcomes, warranting exploration of an accurate method for controlling eccentric and concentric velocity in common barbell exercises.

Lifting Duration Controlled via Metronome

Several of the studies that have evaluated the relationship of eccentric and concentric velocity have utilized a metronome to help subjects control the eccentric and concentric phases of their lifts. Using this method, Bentley et al. observed that force production was more dependent on descent (eccentric) speed than ascent (concentric) speed in the barbell back squat (3), indicating the impact of eccentric velocity on overall lifting performance. An important aspect that this study and many like it (1,12,38,42) lack is an objective validation that subjects effectively matched the metronome rate. Fortunately, Moras et al. observed that subjects accurately timed eccentric and concentric bench press phases to a metronome validated by a linear position transducer (34). However, Bentley et al. and Moras et al. controlled for both eccentric and concentric phases, leaving the question of how controlled eccentric durations may affect natural concentric velocity.

Stretch Shortening Cycle

Plyometric and explosive exercise movements use a prestretch, or countermovement, that involves the stretch shortening cycle (SSC) to maximize performance (47). Interestingly, SSC capabilities are independent of maximal strength in elite athletes (29), suggesting that SSC actions are unique skills that can be improved. Acutely, SSC actions increase mechanical efficiency, impulse, and power via elastic energy recovery while, chronically, these actions enhance neuromuscular activation and upregulate muscle stiffness (29,43)

The SSC has two components that help increase the power produced during muscle contractions: 1) a mechanical model, the series elastic component, and 2) a neurophysiological model, the stretch reflex (4–6,28).

Series Elastic Component

The series elastic component is comprised of the intrinsic behavior of muscle and tendons to store elastic energy when stretched. If a concentric action immediately follows the eccentric phase of stretching, the muscle releases the stored energy to increase force of the concentric contraction by naturally returning the muscles and tendons to their unstretched configuration (21). The force produced during this concentric contraction as the benefit of the series elastic component is greater than that of an isolated concentric muscle contraction (7,45). If no concentric contraction occurs following the stretch of the eccentric action, or if the eccentric phase is too long, the stored energy is lost as heat (21).

Stretch Reflex

The neurophysiological model of the SSC involves the potentiation, or change in the force-velocity characteristics of the muscle's contractile components because of stretch (13), of the concentric muscle contraction via the stretch reflex (4–6).

Specifically, the stretch reflex is the body's involuntary response to an external stimulus that stretches muscles (22) and occurs in three phases. First, the eccentric phase causes stretching of the muscle and stimulates muscle spindles, which send signals to the ventral root of spinal cord via Type 1a afferent nerve fibers. This is followed by the amortization (transition) phase in which there is a delay between eccentric and concentric contractions and Type 1a afferent nerves synapse with the alpha motor neurons in the ventral root of the spinal cord. The alpha motor neurons then transmit signals to the agonist muscle group. Finally, in the concentric phase, alpha motor neurons stimulate the agonist muscle group, resulting in a reflexive concentric muscle contraction (21).

Time Under Tension

Benefits of the SSC are limited for free weight resistance exercises in that deliberately increasing squat velocity can alter body control and change spinal alignment (19). Therefore, there is likely a point of diminishing returns for the SSC in that too fast of an eccentric velocity harms concentric performance and reduces safety. As a result, athletes may purposely decrease the velocities at which they perform resistance training movements, which increases time under tension (TUT). This creates a new set of issues as increased time under tension acutely increases fatigue and decreases power output (40,46) while chronically diminishing explosive capabilities from longer eccentric durations (33). Further, very slow lifts result in significantly less volume (23), which can negatively affect training adaptations (49). Therefore, it appears that optimizing eccentric velocity during a free-weight resistance training exercise is a balance between moving fast enough to get the full benefit of the SSC and minimize time under tension while moving slow enough to safely perform the lift in a controlled manner.

Resistance Training Biomechanics

Barbell Back Squat

The barbell back squat is a closed kinetic chain exercise (44,48) often utilized in strength training programs to improve lower limb strength, power and function (9,11). The beginning of the exercise starts with the lifter in an upright position with hips and knees near full extension (14) and continues with the lifter descending until "the top surface of the legs at the hip joint are lower than the top of the knees" (25). Following this, the lifter will complete the lift by ascending into the upright position he or she started in. Simultaneous flexion or extension of the hips, knees, and ankles is required to successfully complete the barbell back squat (36).

Bench Press

The bench press is an open kinetic chain exercise commonly used in resistance training programs to increase upper body strength and size. The beginning of the exercise starts with the lifter laying face-up on a bench with their arms at full extension holding a barbell. The lifter will then simultaneously flex the elbow and horizontally extend the shoulder joints, lowering the barbell until the middle of it meets the chest. The lifter will then press the barbell up to the start position by extending the elbows and horizontally flexing the shoulders. Throughout the exercise, the lifter must keep the "head, shoulders and buttocks in contact with the bench surface" and the "feet must be flat on the floor" for the lift to be valid (25).

Conclusion

While there is ample data analyzing eccentric velocity and concentric velocity independently, there is limited data assessing the effects of the former preceding the latter in free weight exercises. Studying this relationship for the barbell back squat and bench press, which are commonly used in resistance training programs, can help establish what eccentric velocities safely maximize concentric performance through the SSC. Using a metronome for athletes to time the eccentric phases of their lifts as well as an objective validation of accurate timing via a linear position transducer are likely effective tools in this effort.

III. METHODOLOGY

Experimental Design

The aim of this study was to examine the effects of varying eccentric durations on ACV, PCV, height at which peak velocity occurred (PCV%), and rating of perceived exertion (RPE) at 60% and 80% of 1RM in the squat and bench press. Subjects reported to the laboratory for a total of four sessions over an 8-day period. For the first visit, subjects completed an informed consent form, training history questionnaire, and health history questionnaire followed by anthropometric (height, body mass, and body fat percentage) measurements. After, subjects completed a standardized 5-minute dynamic warm-up designed to increase the body's core temperature and prepare the muscles for the exercises that were performed. Following the dynamic warm-up subjects completed a squat-specific warm-up (20% projected 1RM x 5 repetitions, 50% x 3, 60% x 1, 70% x 1, 80% x 1, 90% x 1) and 1RM testing for the squat (50). After determining the 1RM in the squat, subjects underwent a familiarization period in which they performed 1 repetition sets for both fast (0.75 times) and slow (2 times)-controlled eccentric phase squats at 60% and 80% of 1RM. Finally, subjects performed the same protocol for the bench press excluding the standardized dynamic warm-up. A bench-specific warm-up (same sets and repetitions as the squat warm-up) was followed by a 1RM test and controlled eccentric phase familiarization sets for the bench press to complete the first session. All sets after 60% projected 1RM in the warm-ups were separated by 3 to 5-minute rest periods.

Seventy-two hours after the first visit, subjects performed the same dynamic warm-up as the first day and a lift-specific warm-up for squat (20% of 1RM x 5, 40% x 3, 50% x 2 repetitions). The purpose of this visit was to determine each lifter's normative eccentric duration at various intensities of 1RM in the squat and bench press. After the squat-specific warm-up, three single-repetition sets were completed at 60 and 80% of 1RM to establish the normative eccentric durations at each intensity for each subject. Once normative sets were completed, familiarization sets (similar to visit 1) were performed. Following the squat protocol, subjects repeated the same sequence to establish normative eccentric durations on the bench press. Three to five minutes of rest were administered between each set.

Forty-eight to 72 hours after visit two subjects returned to the lab for visit three, which served as the first experimental session. Following a warm-up, subjects completed either fast or slow (counterbalanced with fourth visit) eccentric velocity squat sets by matching the downward portion of their repetitions to a visual and auditory metronome (Metronome Beats, London, UK) to either 0.75 or 2 times the individual's normative eccentric duration. Three to five-minutes rest were administered between every set. The 2^{nd} experimental session (visit four) occurred 48-72 hours after visit three and followed the exact same procedures as visit three except for performing the opposite duration. A timeline of the protocol can be seen in Table 1.

Subjects were asked to provide an RPE value (Figure 1) (50), which corresponds to repetitions in reserve (RIR) following each set of every session. Further, during each set of every session the Open Barbell System (OBS) (Squats and Science, Brooklyn, NY) recorded the eccentric values of average velocity, ROM, and duration while a second

OBS recorded ACV, PCV, PCV%, and concentric ROM. Subjects were not allowed to view any concentric results until both experimental sessions were completed.

Table 1. Timeline of Events

Day 1	**Day 2** (72hrs after Day 1)	**Day 3** (48-72hrs after Day 2)	**Day 4** (48-72hrs after Day 3)
• HHQ • PAQ • IC • AM • Dynamic Warm-up • 1RM Squat Testing • Squat familiarization sets • 1RM Bench Testing • Bench familiarizations sets	• Dynamic warm-up • Squat normative 60% sets • Squat normative 80% sets • Squat familiarization sets • Bench normative 60% sets • Bench normative 80% sets • Bench familiarization sets	• Dynamic warm-up • Squat fast/slow 60% sets • Squat fast/slow 80% sets • Bench fast/slow 60% sets • Bench fast/slow 80% sets	• Dynamic warm-up • Squat fast/slow 60% sets • Squat fast/slow 80% sets • Bench fast/slow 60% sets • Bench fast/slow 80% sets

Health History Questionnaire (HHQ), Physical Activity Questionnaire (PAQ), Informed Consent (IC), Anthropometric Measurements (AM), 1-Repetition Maximum (1RM), All fast or all slow sets counterbalanced between days 3 and 4 (fast/slow).

RESISTANCE EXERCISE-SPECIFIC RATING OF PERCIEVED EXERTION (RPE)

Rating	*Description of Perceived Exertion*
10	*Maximum effort*
9.5	*No further repetitions but could increase load*
9	*1 repetition remaining*
8.5	*1-2 repetitions remaining*
8	*2 repetitions remaining*
7.5	*2-3 repetitions remaining*
7	*3 repetitions remaining*
5-6	*4-6 repetitions remaining*
3-4	*Light effort*
1-2	*Little to no effort*

Figure 1. Repetitions in Reserve-Based RPE Scale

Subjects

Subject characteristics are displayed in Table 2. Sixteen resistance trained males participated in the current study. However, only 15 subjects' training ages were used for analysis as one subject failed to report specific training age. For inclusion, all subjects must have performed the squat and bench press exercises on average once per week for the previous two years as determined by a validated physical activity questionnaire (50). Subjects must have been able to squat 1.5 times their body mass (BM) and bench press at least their BM. Subjects who had contraindications to exercise (i.e. heart disease, serious musculoskeletal disorders, injuries, etc.) as determined via the Health History Questionnaire were excluded from participation. Additionally, subjects had to refrain from exercise 48 hours prior to the first session and for the duration of the study thereafter. The University's Institutional Review Board approved this investigation prior to data collection and all subjects provided written consent prior to participation.

Table 2. Subject Characteristics (N=16)

	Age (y)	**Training Age (y)**	**Height (cm)**	**Body Mass (kg)**	**Body Fat %**	**Squat 1RM (kg)**	**Bench Press 1RM (kg)**
Mean	23.25	6.99	171.82	81.96	9.73	151.8	119.7
SD	2.57	3.59	7.48	12.16	4.61	49.6	26.2
Max	30	15	184	106.04	19.58	278.5	187.5
Min	20	2.83	161.8	60.26	3.97	91	80.5

1RM= One Repetition Maximum.

Procedures

Anthropometric Assessments

Total BM (kg) was measured by a calibrated digital scale (Mettler-Toledo, Columbus, Ohio, USA) and body fat percentage (BF%) was estimated using the average sum of three skinfold thickness measurements acquired at three separate sites (chest, abdomen, anterior thigh). The Jackson Pollock equation was used to calculate BF% (26). All anthropometric measurements were assessed by the same investigator.

Squat and Bench Press Execution

For the squat, subjects stood straight with their hips and knees locked, and the barbell placed across their upper back/shoulders. After receiving an audible “squat” command from an investigator, they descended with the bending of the knees until the top of their leg at the hip joint was below the top of their knee. Then they returned to their starting position on their own volition and upon receiving an audible “rack” command returned the weight to the rack. For the bench press, subjects laid chest up on a flat bench with a barbell in their closed hands. After receiving an audible “start” command they descended with the bending of the elbows until the bar touched their chest in a controlled manner. Then they returned to their starting position upon their own volition and re-racked the weight after receiving an audible “rack” command.

One-Repetition Maximum (1RM) Testing

All 1RM testing was conducted in accordance with previously validated procedures (50). Squat and bench press testing was completed in that order during the first session in accordance to the National Strength and Conditioning Association (NSCA) guidelines, and both exercises were performed to the rules set by the United States of America Powerlifting (USAPL). Testing for each exercise began by the subject performing a lift-specific warm-up (20% projected 1RM x 5 repetitions, 50% x 3, 60% x 1, 70% x 1, 80% x 1, 90% x 1) followed by increases in subsequent 1RM attempts with loads determined at the investigator's discretion. To aid in attempt selection, ACV and rating of RPE were collected on each warm-up set and 1RM attempt. Subjects completed warm-up sets at their own volition until their 70% of projected 1RM set, at which point they were allowed 3 to 5-minute rest periods between sets until the completion of 1RM testing. A 1RM attempt was considered valid if one of the following conditions were met: 1) Subject reported a '10' on the RIR/RPE scale and the investigator determined a subsequent attempt with increased weight could not be successfully or safely completed, 2) subject reported a '9.5' on the RIR/RPE scale and missed the subsequent attempt with a load increase of 2.5kg or less, 3) subject reported a '9' or lower on the RIR/RPE scale and failed the subsequent attempt with a load increase of 5kg or less. All successive increases in load following the 90% 1RM performance were required to be less than or equal to the previous attempt's increase in load. Lastly, calibrated Eleiko barbells and lifting discs (Chicago, Illinois, USA) were used for valid measures of loads lifted.

Fast and Slow Eccentric Duration Variations

To control for eccentric duration, subjects squatted to both an auditory and visual metronome that was set to the appropriate tempo at which the desired eccentric duration would last between beats. For example, if a subject naturally completed the eccentric phase in one second, then a metronome would be set to have 0.75 s between beats for the fast condition and two s between beats for the slow conditions, resulting in 80 and 30 beats per minutes, respectively. Subjects were allowed off-beats to help them better pace their descent if requested. Subjects were encouraged to ascend as fast as possible during the concentric phase. The eccentric durations used for the familiarization period in the first session were the durations produced with loads closest to 60% and 80% of actual 1RM during the warm-up sets. The eccentric durations used for the familiarization period in the second session as well as sessions 3 and 4 were the averages of the eccentric durations for the three normative sets completed in the second session. For the squat, the auditory and visual metronome was placed at a comfortable height determined by each subject on a bench in front of them. For the bench press, only the auditory feature of the metronome was used to avoid the hazard of placing equipment above the subjects during this lift.

Statistical Analyses

To examine differences between conditions (normative eccentric, fast eccentric, and slow eccentric) a one-way analysis of variance (ANOVA) was used for each outcome variable (ACV, PCV, PCV%, RPE, and concentric ROM). Further, Pearson's product moment correlations were used to examine associations between eccentric phase duration and all outcomes variables at 60 and 80% of 1RM in the squat and bench press. Correlation coefficient r scores and their associated p values quantified these associations. Correlations were interpreted and reported as "weak" if they were less than or equal to 0.35, "moderate" if they were between 0.36 to 0.67, "strong" if they were between 0.68 to 0.89, and "very strong" if they were equal or greater than .90. The coefficient of determination r^2 score was also calculated to express the explained variance of the correlation coefficients. To express the potential range of concentric outcome measures recorded at each intensity mean, standard deviation, and 90% confidence limits (CLs) were calculated. All statistical analyses were performed using Statistica for Windows (StatSoft; Tulsa, OK, USA) and the level of significance was set at $p \leq 0.05$.

IV. RESULTS

Compliance with Goal Eccentric Durations

Prior to the assessment of any correlations, reliability analyses using paired t-tests were performed to ensure that subjects produced eccentric durations matching the goal eccentric durations for the experimental sets. All t-tests produced p-values ≥0.481, indicating no significant differences between the goal eccentric durations and actual eccentric durations produced by subjects during fast and slow eccentric duration conditions

Normative Eccentric Durations

At 1RM in squat and bench press the average eccentric durations were 1.401 ± 0.307 s and 1.191 ± 0.252 s, respectively. Additionally, at 80% of 1RM squat and bench press the average eccentric durations for the normative profile were 1.324 ± 0.309 s and 1.107 ± 0.279 s, respectively. At 60% of 1RM squat and bench press the average eccentric durations for the normative profile were 1.213 ± 0.332 s and 1.056 ± 0.317 s, respectively. Further, there were no significant differences for normative eccentric durations across all intensities for both squat (p=0.262) and bench press (p=0.405).

Relationship Between Eccentric Durations and Concentric Outcomes

The bivariate correlations examined relationships between all eccentric durations and concentric outcomes across all three conditions (i.e. combined cohort). The associated r- and p-values for these correlations are displayed in Table 3. There were significant inverse correlations between eccentric duration with ACV at 60% (r = –0.408) and 80% (r = –0.477) of 1RM squat, indicating that a faster eccentric (i.e. shorter duration) was related to greater ACV. This relationship was also found in the bench press at 100% of 1RM (r = –0.604). The only other significant correlation was between eccentric duration and PCV% at 80% of 1RM squat (r = 0.318) , indicating that a faster eccentric was related to a lower PCV%. Correlations between eccentric duration and the following outcome measures approached significance: RPE at 80% of 1RM squat, ACV at 80% of 1RM bench press, PCV at both 80% and 100% of 1RM bench press, and PCV% at 60% of 1RM bench press. No significant relationships existed between eccentric durations and RPE, eccentric ROM, PCV, or concentric ROM ($p>0.05$). Significant correlations between eccentric durations and concentric outcomes are expressed as correlation regressions in Figure 2.

Table 3. Correlations Between Eccentric Duration and Outcome Measures for the Squat and Bench press (N=48)

Ecc Duration Condition		***RPE***	***Ecc ROM***	***ACV***	***PCV***	***PCV%***	***Con ROM***
60% Squat	*Correlation r*	0.1800	-0.0991	**-0.4078***	-0.1483	0.0726	-0.0515
	P Value	0.221	0.503	**0.004***	0.314	0.624	0.728
80% Squat	*Correlation r*	0.2725	-0.0646	**-0.477***	-0.1445	**0.3175***	-0.1123
	P Value	0.061**	0.663	**0.001***	0.327	**0.028***	0.447
100% Squat #	*Correlation r*	-0.0291	-0.399	-0.0812	-0.0153	-0.3253	-0.3213
	P Value	0.918	0.141	0.773	0.957	0.237	0.243
60% Bench	*Correlation r*	0.1205	-0.2012	-0.1928	-0.1859	0.0977	-0.2160
	P Value	0.415	0.170	0.189	0.206	0.509**	0.140
80% Bench	*Correlation r*	0.2136	-0.0577	-0.2738	-0.2635	0.1523	-0.0807
	P Value	0.145	0.697	0.060**	0.070**	0.301	0.586
100% Bench	*Correlation r*	0.0590	-0.1866	**-0.6035***	-0.4748	0.1429	-0.0950
	P Value	0.828	0.489	**0.013***	0.063**	0.598	0.726

Bold*= Significant Correlation; **= Approaching Significant Correlation; #N=15; Ecc= Eccentric; Con = Concentric; RPE= Rating of Perceived Exertion; ROM= Range of Motion; ACV= Average Concentric Velocity; PCV= Peak Concentric Velocity; PCV%= Concentric height at which peak velocity occurred. Level of significance $p \leq 0.05$.

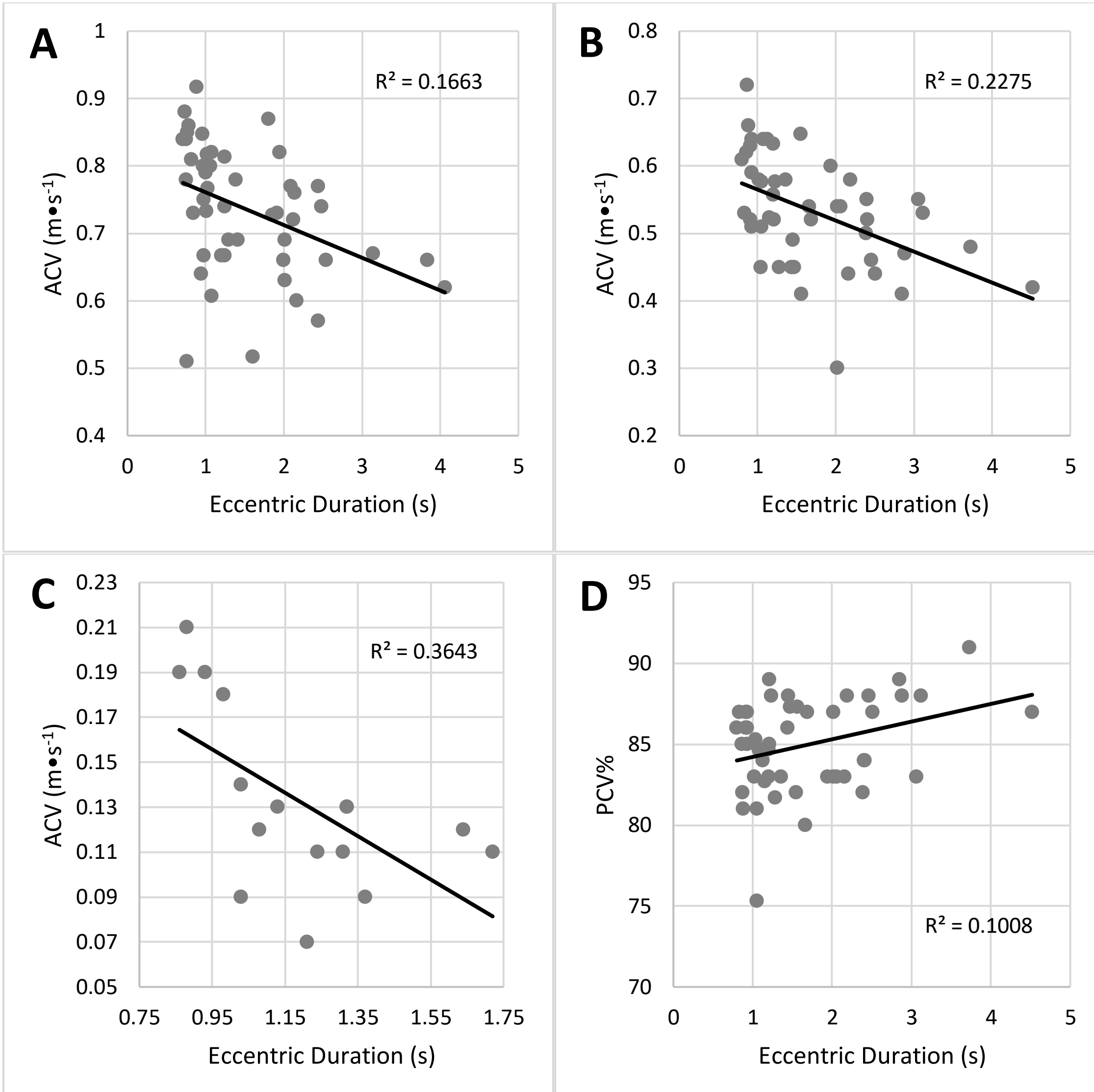

Figure 2. Significant Correlations Between Eccentric Duration and Outcome Measures in the Squat and Bench Press. ACV= Average Concentric Velocity; PCV%= height at which peak velocity occurred. ***A****) 60% of 1RM Squat.* ***B****) 80% of 1RM Squat.* ***C****) 100% of 1RM bench press.* ***D****) 80% of 1RM squat.*

Between Condition Comparisons

Squat Comparisons

The specific between values for between condition comparisons for all concentric outcomes can be seen in Table 4. For both 60% and 80% of 1RM squat, ACV from fast eccentric conditions was found to be significantly faster (p=0.033 and p=0.002, respectively) than slow conditions and approaching significantly faster ($p=0.081$ and $p=0.056$, respectively) than normative conditions. At 60% of 1RM squat, both fast and slow eccentric conditions produced greater ($p<0.001$) PCV than normative with fast also producing greater ($p=0.044$) PCV than slow. The following comparisons approached a significant difference at 80% of 1RM in the squat: fast condition had greater PCV than normative, slow condition had higher PCV% than normative, and slow condition had higher RPE than normative.

Bench Press Comparisons

The only significant difference found between bench press conditions was 60% of 1RM slow condition had greater ($p=0.049$) PCV than normative. The following comparisons approached a significant difference at 60% of 1RM in the bench press: fast condition had greater ACV than normative, fast condition had greater PCV than normative, and slow condition had higher PCV% than normative. There were no significant or approaching significant differences between conditions at 80% of 1RM bench press.

Table 4. ANOVA Between Condition Comparisons for Normative, Fast, and Slow Eccentric Duration Conditions in the Squat and Bench Press.

Intensity and Lift	Outcome Measure	Condition	Means ± standard deviation	Finding	Post-hoc P values	Effect Size	Percentage difference
60% 1RM Squat	ACV ($m \cdot s^{-1}$)	Normative	0.720 ± 0.104	F > S	0.033*	0.84	9.16%
		Fast	0.778 ± 0.088	F > N	0.081**	0.60	7.42%
		Slow	0.707 ± 0.081				
	PCV ($m \cdot s^{-1}$)	Normative	0.720 ± 0.104	F > N	<0.001*	4.56	44.24%
		Fast	1.292 ± 0.143	S > N	<0.001*	3.04	39.08%
		Slow	1.183 ± 0.188	F > S	0.044*	0.65	8.47%
80% 1RM Squat	ACV ($m \cdot s^{-1}$)	Normative	0.528 ± 0.077	F > S	0.002*	1.19	14.98%
		Fast	0.580 ± 0.071	F > N	0.056**	0.70	8.9%
		Slow	0.493 ± 0.076				
	PCV ($m \cdot s^{-1}$)	Normative	0.959 ± 0.160	F > N	0.067**	0.67	9.71%
		Fast	1.063 ± 0.146				
		Slow	0.980 ± 0.161				
	PCV%	Normative	84.0 ± 3.3	S > N	0.060**	0.64	2.25%
		Fast	84.9 ± 2.4				
		Slow	85.9 ± 2.7				
	RPE	Normative	5.45 ± 1.29	S > N	0.097**	0.68	14.58%
		Fast	5.81 ± 1.86				
		Slow	6.38 ± 1.44				
60% 1RM Bench Press	ACV ($m \cdot s^{-1}$)	Normative	0.563 ± 0.083	F > N	0.062**	0.67	9.64%
		Fast	0.623 ± 0.096				
		Slow	0.614 ± 0.086				
	PCV ($m \cdot s^{-1}$)	Normative	0.768 ± 0.109	S > N	0.049*	0.71	10.24%
		Fast	0.845 ± 0.120	F > N	0.082**	0.67	9.11%
		Slow	0.855 ± 0.136				
	PCV%	Normative	66.9 ± 14.2	S > N	0.089**	0.57	9.77%
		Fast	72.5 ± 9.6				
		Slow	74.2 ± 11.2				

Table only shows post-hoc results, effect sizes, and percentage difference for significant or approaching significant findings. *= Significant Correlation. **= Approaching Significant Correlation. 1RM= One Repetition Maximum. ACV= Average Concentric Velocity. PCV= Peak Concentric Velocity. PCV%= Height at which peak concentric velocity occurred. RPE= Rating of Perceived Exertion. N= Normative Eccentric Condition. F= Fast Eccentric Condition. S= Slow Eccentric Condition.

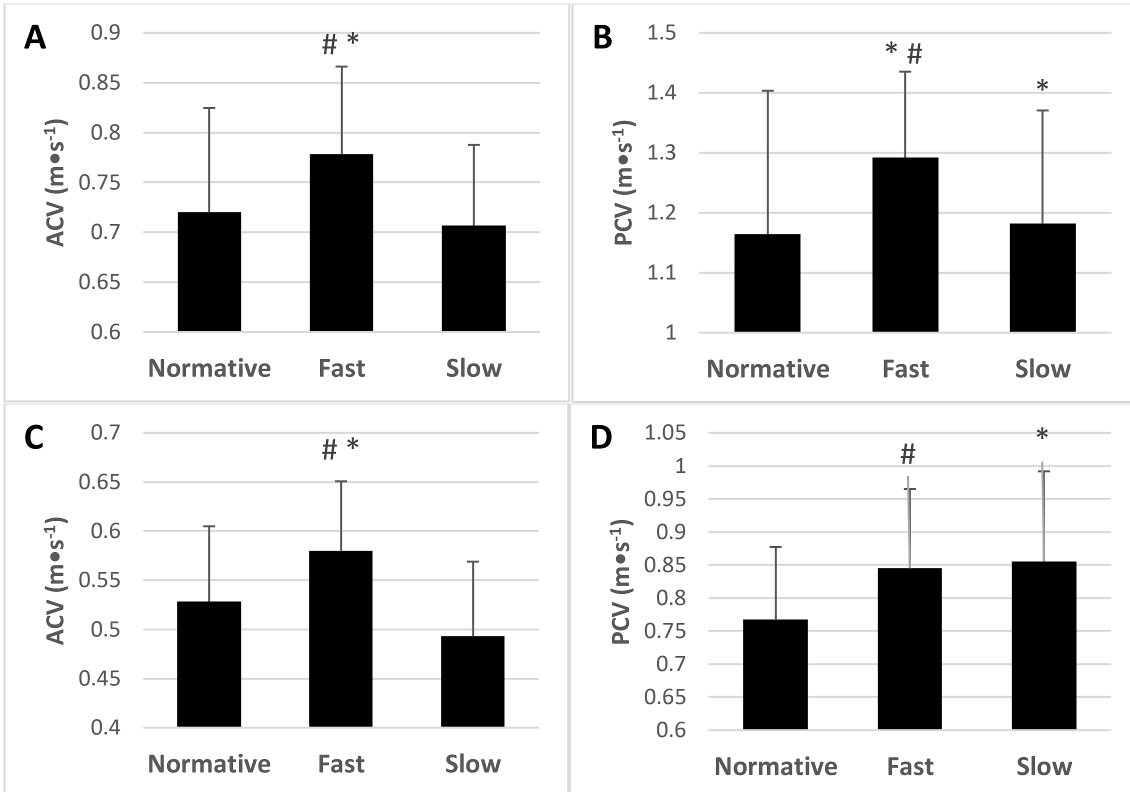

Figure 3. Differences in Average and Peak Concentric Velocity at 60% and 80% of One Repetition Maximum for Normative, Fast, and Slow Eccentric Duration Conditions in the Squat and Bench Press. Data presented as means ± standard deviations. ACV = Average Concentric Velocity; PCV = Peak Concentric Velocity. ***A****) ACV at 60% of 1RM Squat. *= significantly faster than Slow. # = approaching significantly faster than Normative.* ***B****) PCV at 60% of 1RM Squat. *= significantly faster than Normative. # = significantly faster than Slow.* ***C****) ACV at 80% of 1RM Squat. *= significantly faster than Slow. # = approaching significantly faster than Normative.* ***D****) PCV at 60% of 1RM Bench Press. *= significantly faster than Normative. # = approaching significantly faster than Normative.*

V. DISCUSSION

To our knowledge, this is the first study to investigate the relationship between variations in eccentric phase duration and concentric outcomes in the squat and bench press. Our first hypothesis was partially supported in that fast eccentric durations produced faster ACV at 60% and 80% of 1RM squat and faster PCV at 60% of 1RM squat compared to slow and normative eccentric conditions. However, our second hypothesis was not supported in that slow eccentric durations did not result in slower ACV, slower PCV, higher RPE values, or decreased ROM compared to normative and fast conditions for either lift. Surprisingly, slow eccentric conditions produced several concentric outcomes more favorable than normative conditions; specifically, greater PCV at 60% of 1RM for both squat ($p<0.001$) and bench press ($p<0.049$). Overall, these data suggest that a fast eccentric phase on the squat and bench press is related to improved concentric performance, specifically as it relates to ACV, which is the most common velocity variable utilized by practitioners.

The present findings revealed fast eccentric durations to produce 44.24% and 8.47% faster PCV than normative and slow conditions, respectively, at 60% of 1RM squat. Further, fast eccentric durations produced 9.16% and 14.98% faster ACV than slow conditions at 60% and 80% of 1RM squat, respectively. Interestingly, despite achieving faster ACV and PCV during fast eccentric conditions, subjects did not record lower RPE scores (i.e. lower perception of effort) in the fast condition. On the other hand, RPE is a product of the entire movement (eccentric and concentric), and deliberately altering a subjects' eccentric movement velocity did not increase RPE scores. Further, previous data has indicated RIR-based RPE to decrease in accuracy with more RIR and when gauged after only one repetition in a set (24,35,50), thus the improved ACV and stable RPE suggests a possible benefit of performing an eccentric squat at 0.75 times one's normative rate. Interestingly, despite no differences in PCV between conditions, a significant correlation (r=0.318, p=0.028) was observed between eccentric duration and PCV% at 80% of 1RM squat, indicating that longer eccentric durations resulted in greater PCV%. Given that ACV increased with faster eccentric durations, this finding may indicate achieving PCV at a lower height increases ACV at 80% of 1RM squat. This likely resulted from the ACV being closer to PCV throughout more of the concentric ROM. Additionally, the fact that PCV did not change between conditions suggests a narrow PCV range exists at 80% of 1RM squat regardless of eccentric duration.

For the bench press exercise, our findings suggest that eccentric durations more greatly influenced concentric outcomes at 60% of 1RM compared to 80% of 1RM. This was evident from fast eccentric durations approaching significantly faster ACV (p=0.062, ES=0.667) and PCV (p=0.082, ES=0.671) versus the normative condition at 60%, with no meaningful difference between conditions at 80% of 1RM (ACV p=0.667; PCV p=0.325). Conversely, slow eccentric durations produced significantly faster PCV (p=0.049) than normative durations at this same intensity, perhaps indicating slower eccentric durations more effectively primed subjects' explosive capabilities for the concentric phase. This counterintuitive finding suggests that the stretch shortening cycle's effects on bench press performance are diminished at lighter intensities. At maximal intensity, however, the stretch shortening cycle appears to benefit concentric performance as eccentric duration was moderately and inversely correlated (r=–0.604, p=0.013) with ACV at 100% of 1RM bench press. Interestingly, the four subjects who descended in the shortest duration at 1RM in the bench press also had the four fastest ACVs. Since ACV at a 1RM bench press decreases as an athlete becomes more experienced (35), this finding may indicate that faster eccentric durations increase ACV at a 1RM only when an athlete has achieved sufficient experience and technical mastery with the bench press.

Collectively, our observation of no significant differences between normative eccentric durations at 60%, 80%, and 100% of 1RM for either squat or bench press are preliminary. Subjects produced greater eccentric durations at 100% of 1RM compared to 60% of 1RM squat (p=0.11, ES=0.59), indicating greater eccentric control is required to complete a squat at 100% of 1RM compared to submaximal intensities. Interestingly, the least significant difference between normative eccentric durations occurred between 60% and 80% of 1RM bench press (p=0.612, ES=0.172), perhaps showing less variation in eccentric duration is required at submaximal repetitions in the bench press compared to the squat. Additionally, our finding that slow eccentric durations produced faster PCV at 60% of 1RM for both squat (p=0.033) and bench press (p=0.049) indicate that resistance-trained males do not produce maximal concentric effort during normative submaximal repetitions. This likely resulted from subjects being instructed to complete the normative repetitions on their own volitional effort, whereas they were encouraged to complete the concentric phases of their fast and slow eccentric repetitions with maximal effort. This protocol was used because during pilot testing investigators noticed subjects who were instructed to complete the concentric phase of their normative repetitions as fast as possible often increased their eccentric velocity in this effort, and, ultimately, did not produce truly normative repetitions. However, if during the fast and slow conditions subjects were instructed to match the metronome pace during the eccentric phase and then complete the concentric phase on their own volition, this would not have represented their maximal possible capabilities in these conditions. This was likely the greatest contributing factor towards subjects producing greater PCV during slow eccentric repetitions at 60% of 1RM for both squat (39.08%, $p<0.001$) and bench press (10.24%, $p=0.049$) compared to normative repetitions.

Several limitations existed in this study. Only using trained, college-aged males narrows the practical applications of these findings to that population. Additionally, the current study only analyzed the squat and bench press during single repetition sets, thus it is not known if the present results would be the similar in single-joint exercises or in multiple repetition sets. The present study only assessed 60% and 80% of 1RM and 0.75 times and two times normative eccentric duration variations for each lift. It is possible that eccentric duration has a greater or diminished impact on concentric outcomes through the stretch-shortening cycle at different intensities and different variations of a lifter's normative eccentric duration, which this study failed to assess.

In summary, our data demonstrate that for some, but not all, a faster eccentric contraction may facilitate improved ACV in the squat and bench press at submaximal intensities. Importantly, individuals who already have a fast descent on the squat and bench press may have already maximized the stretch reflex, thus an even more rapid descent could be harmful. Presently we observed normative eccentric durations of approximately 1.0-1.4 s across conditions, thus if an individual's eccentric duration is already <1.0 s a faster duration cannot yet be recommended. Further, the present study did not explore the practicality of controlling for eccentric duration with a metronome at 1RM in the bench press due to an assumed increased risk of injury with altering performance at maximal loads. It must be stated that these results are preliminary and more data is needed to individualize eccentric durations. However, these results do suggest that an eccentric phase should be performed at a duration that maximizes concentric performance and that an auditory and visual metronome can be used to effectively accomplish this.

APPENDICES

Appendix A: Approval Letter

FLORIDA ATLANTIC UNIVERSITY

Institutional Review Board
Division of Research
777 Glades Rd.
Boca Raton, FL 33431
Tel: 561.297.1383
fau.edu/research/researchint

Michael Whitehurst, Ed.D., Chair

DATE:	October 31, 2017
TO:	Michael Zourdos, Ph.D.
FROM:	Florida Atlantic University Health Sciences IRB
IRBNET ID #:	1137167-3
PROTOCOL TITLE:	[1137167-3] The effects of eccentric phase duration on concentric phase performance in the squat and bench press
PROJECT TYPE:	*New Project*
ACTION:	APPROVED
APPROVAL DATE:	October 30, 2017
EXPIRATION DATE:	October 30, 2018
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *B4*

Thank you for your submission of Response/Follow-Up materials for this research study. The Florida Atlantic University Health Sciences IRB has APPROVED your *New Project*. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

- This study is approved for a maximum of **40** participants.
- It is important that you use the approved, stamped consent documents or procedures included with this letter.
  - Adult Consent Form - Eccentric Consent Revision, Version 3.0, October 27, 2017 (stamped)
  - Protocol - Eccentric Protocol Form 1A Revision (stamped)
- ****Please note that any revision to previously approved materials or procedures, including modifications to numbers of subjects, must be approved by the IRB before it is initiated.** Please use the amendment form to request IRB approval of a proposed revision.
- All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All regulatory and sponsor reporting requirements should also be followed, if applicable.
- Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.
- Please note that all research records must be retained for a minimum of three years.
- **This approval is valid for one year.** A Continuing Review form will be required prior to the expiration date if this project will continue beyond one year.

If you have any questions or comments about this correspondence, please contact Donna Simonovitch at:

Institutional Review Board
Research Integrity/Division of Research
Florida Atlantic University
Boca Raton, FL 33431
Phone: 561.297.1383
researchintegrity@fau.edu

* Please include your protocol number and title in all correspondence with this office.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within our records.

Appendix B: Informed Consent

ADULT CONSENT FORM

Consent Form Version & Date: Version 3.0: October 27th, 2017.

1) Title of Research Study: The effects of eccentric phase duration on concentric phase performance in the back squat and bench press.

2) Investigator(s): Michael C. Zourdos, Ph.D., CSCS, Joseph P. Carzoli, B.S., CSCS, Colby A. Sousa, B.S., CSCS, Daniel J. Belcher, B.S., CSCS.

3) Purpose: The purpose of this research study is to examine if eccentric phase duration (i.e. time to descend) effects concentric phase performance in the back squat and bench press exercises.

4) Procedures: If you choose to participate in this study you will be required to complete the following assessments among four laboratory visits:

- One repetition maximum (1RM) strength in the squat and bench press
- Eccentric Duration-Profile Assessment in the squat and bench press
- Fast sets in the squat and bench press
- Slow sets in the squat and bench press
- Body composition by skinfold caliper (chest, abdomen, thigh)
- Anthropometrics (femur length, forearm length, height & weight)

All measurements will be conducted by the principal investigator or graduate assistants working within the Muscle Physiology Laboratory (i.e. the principal investigator will not always be present). For the first visit, you will be required to complete an informed consent form, training history questionnaire, and health history questionnaire followed by anthropometric (height, body mass, upper arm length, forearm length, and total arm length) and body composition (skinfolds; chest, abdomen, thigh) measurements. Afterwards, you will complete a standardized 10-minute dynamic warm- up routine designed to increase the body's core temperature and prepare the muscles for exercises that will be performed. Following the warm-up, you will complete a squat-specific warmup (20% projected 1RM x 5, 50% x 3, 60% x 1, 70% x 1, 80% x 1, % x 1). Next, one-repetition maximum (1RM) testing for the squat will begin. All 1RM tests will be administered with accordance to the National Strength and Conditioning Association (NSCA) guidelines, and all exercises will be performed to the rules set by the United States of America Powerlifting (USAPL). After determining the 1RM in the squat, a 3-minute rest period will precede a bench-specific warmup (same protocol described for squat-specific warmup), followed by a 1RM test for the bench press. All 1RM attempts will be separated by 3 to 5-minute rest periods. Following the 1RM tests you will undergo a familiarization period in which you will perform 1 set of 1 repetition for both fast (0.75 times the normal duration) and slow (2 times the normal duration)-controlled eccentric contractions for both exercises at 60 and 80% of 1RM. The varying eccentric durations will be based on your normal eccentric duration which will be recorded during your warm-up and 1RM attempts earlier in this session. To perform the controlled eccentric phase during the familiarization your duration will be controlled with a visual and auditory metronome. You will then perform the concentric phase, following the eccentric phase, as fast as possible.

Participant Initials ________

FAU Institutional Review Board

1137167-3	
Approved On:	October 30, 2017
Expires On:	October 30, 2018

Next, 72 hours following the first visit you will perform the same dynamic warm-up as on day 1 and lift-specific warm-up for the squat (i.e. 20% of 1RM X 5 repetitions, 40% of 1RM X 3 repetitions, 50% of 1RM X 2 repetitions, and later perform 70% of 1RM X 1 repetition in-between tested 60% and 80% sets).

The purpose of the second visit is to solely determine your normative eccentric duration at 60 and 80% of 1RM on the squat and bench press.

Thus, after the squat specific warm-up you will perform three single-repetitions sets at 60 and 80% of 1RM at your normal eccentric duration.

There will be 3 minutes between each set and eccentric duration along with concentric velocity and power output will be tracked on each set.

There will be 3 minutes rest between the end of the squat protocol and then this process will be repeated for the bench press. Following the bench press you will again perform a familiarization which will consist of 1 set of 1 repetition at each the fast (0.75 times the normal duration) and slow (2 times the normal duration) eccentric duration at each intensity (60 and 80%) of 1RM for both the squat and bench press. Again, a visual and auditory metronome will be used to control the eccentric duration during this familiarization and 3 minutes rest will be administered between each set.

Forty-Eight hours after visit two you will return to the lab for visit three, which will serve as the first experimental session to determine the relationship of either slow or fast eccentric squat and bench with concentric performance. Again, you will first complete the dynamic warm-up and lift-specific warm- up for the squat. You will then complete either fast or slow (randomized with fourth visit) eccentric velocity squat sets by matching the downward portion of your repetitions to a visual and auditory metronome timed to a specific percentage of your normative eccentric duration values found on the second visit. To examine slow eccentric contractions, you will perform three sets of one repetition at twice the eccentric duration established in your normative profile from laboratory visit two. For example, if your normative eccentric duration is one second the visual and auditory metronome will be set to an eccentric duration of two seconds. To examine fast eccentric contractions, you will perform three sets of one repetition at an eccentric duration of 75% of your normative value established during visit two. For example, if your normative eccentric duration is one second the visual and auditory metronomes will be set to an eccentric duration of 0.75 s. This process will be repeated for bench press. Forty-eight hours will separate the third and fourth sessions and 3 minutes rest will be administered between every set.

For the fourth visit, you will complete the same protocol performed during the third visit but you will complete sets at the pace you did not complete during the third visit (fast or slow). All four laboratory visits will take about 3 hours each to complete and no longer than 3.5 hours.

For the squat, you will stand straight with your hips and knees locked, and the barbell placed across your upper back/shoulders. You will then descend with the bending of the knees until the top of your leg at the hip joint is below the top of your knee. Then you will return to your starting position upon your own volition.

Participant Initials ________

For the bench press, you will lay chest up on a flat bench with a barbell in your closed hands. you will then descend with the bending of the elbows until the bar touches your chest in a controlled manner. Then you will return to your starting position upon your own volition.

You will be asked to provide a rating of perceived exertion (RPE) value, which corresponds to repetitions in reserve (how many more repetitions you could do at the completion of the set) following each lifting set during each session. Further, during each set of every session the Open Barbell System (Squats and Science, Brooklyn, NY) linear position transducer will record average concentric velocity, peak concentric velocity, peak concentric power, and average eccentric velocity.

Finally, lifts completed during this study will also be video recorded and analyzed for the movement of the bar path. This outcome measure will allow us to examine if fast or slow eccentric durations effect the biomechanics of movement compared to a normal eccentric duration. Lifts will be recorded from the lateral aspect with a smartphone to analyze the movement path of the barbell.

Recordings will not be shared with anyone other than the investigators or used for any other purposes. Videos will be stored solely on the primary investigator's computer.

5) <u>Risks:</u>

Anytime you engage in exercise there are some inherent risks including: muscle strains, soreness, or joint aches. Since you will perform resistance exercise, the muscle soreness caused by muscle damage may be experienced within 24 to 48 hours.

If muscle soreness does occur, it should be eased after 48 or 72 hours. The investigators will assure that you can meet the movement standards before proceeding with data collection; however, risk of injury is always present during resistance exercise.

If an injury does occur you will notify the principal investigator if present, if not you will notify a graduate research assistant whom will immediately notify the principal investigator. The principal investigator will then stay in consistent contact with you in regards to your well-being. If serious injury or an emergency situation occurs during training, the investigators will immediately contact student health services if you are a student and if you are not a student the investigators will call your primary care physician or 911 if necessary. Finally, there is a small risk of breach of confidentiality.

Further, there is a small risk of breach of confidentiality, however, to minimize this risk a code number will be assigned to you and only Dr. Michael Zourdos, Ph.D., CSCS will keep a record with your name and code number, in a locked file drawer. The computer with the recorded data will be password protected so there will be no access to electronic data. All data (hard copy and computer) will be destroyed in 10 years.

6) <u>Benefits:</u>

The potential benefits to you are:

- Free measurements of body composition and 1RM testing
- Access to calibrated training equipment that is approved by and used within the International Powerlifting Federation (IPF) competitive events

Participant Initials ________

7) Compensation for Injury:

If you are injured or get sick as a result of the study procedures, you should obtain medical treatment and then notify the study Principal Investigator. Payment for this medical treatment is not available from the study researchers. You, or any available health insurance you have, will be billed for this treatment. Your health insurance company may not pay for treatment of injuries as a result of your participation in this study. Also, no funds are available to pay any wages you may lose if you are harmed by this study.

Further, if an injury or illness does occur in the laboratory during the study the investigators will cease study participation and contact student health services immediately.

8) Data Collection & Storage:

Potentially identifiable information about you will consist of a medical history questionnaire and research data sheets. Data are being collected only for research purposes. All personal identifying information will be kept in password-protected files and a code number will be used for identification purposes. Data records will be kept in a locked file cabinet in an office within the department of Exercise Science and Health Promotion. Although results of this research may be presented at meetings or in publications, identifiable personal information pertaining to participants will not be disclosed unless required by law.

9) Contact Information:

- If you have questions about the study, you should call or email the investigator(s), Michael C. Zourdos, at (561)-297-1317 or mzourdos@fau.edu.

- If you have questions or concerns about your rights as a research participant, contact the Florida Atlantic University Division of Research, Research Integrity Office at (561) 297-1383 or send an email to researchintegrity@fau.edu.

10) Consent Statement:

*I have read or had read to me the information describing this study. All my questions have been answered to my satisfaction. I am 18 years of age or older and freely consent to participate. I understand that I am free to withdraw from the study at any time without penalty. I have received a copy of this consent form.

Printed Name of Participant: ____

Signature of Participant: _________________________________ Date: _________________

Printed Name of Investigator: _______________________________________

Signature of Investigator: _______________________________ Date: _________________

FAU Institutional Review Board

1137167-3	
Approved On:	October 30, 2017
Expires On:	October 30, 2018

Appendix C: Health History Questionnaire

Florida Atlantic University

Medical History Form

Demographics:
Name: _______________________________ Sport: ___________ Pos.: _______________
Date: ___________ Age: _______________ Birth Date: ____/____/____

Family History:
Has anyone in your immediate family had any of the following: Please circle yes or no.

Heart Disease	Yes	No	Diabetes	Yes	No
High Blood Pressure	Yes	No	Cancer	Yes	No
Stroke	Yes	No	Tuberculosis	Yes	No
Sudden Death (before 50)	Yes	No	Asthma	Yes	No
Epilepsy	Yes	No	Gout	Yes	No
Migraine Headaches	Yes	No	Marfan's Syndrome	Yes	No
Eating Disorder	Yes	No	Sickle Cell	Yes	No

Personal History:

1. Have you ever been hospitalized? Yes No
   Have you ever had surgery? Yes No
   Are you presently under a doctor's care? Yes No
   Please explain and give dates for all "Yes" answers: ___________________________________
   ____
   ____

2. Please list any medications you are currently taking and for what conditions. _______________
   ____

3. Please list any known allergies. ____
   ____

4. Have you ever had a head injury / concussion? Yes No
   Have you ever been knocked out or unconscious? Yes No
   Have you ever had a seizure, "fit", or epilepsy? Yes No
   Have you ever had a stinger, burner, or pinched nerve? Yes No
   Do you have recurring headaches or migraines? Yes No
   Pleas explain and give dates of "Yes" answers: _______________________________________
   ____
   ____
   ____

5. Have you ever had the chicken pox? Yes No
   If yes, at what age? _________

6. Have you ever had the mumps or measles? Yes No

7. Do you have a history of asthma? Yes No

8. Are you missing an eye, kidney, lung, or testicle? Yes No

9. Do you have any problems with your eyes or vision? Yes No

10. Have you ever had any other medical problems (mononucleosis, diabetes, anemia)? Yes No

11. Have you ever taken any supplements for improved performance? Yes No

12. Are you presently taking any supplements for diet or performance? (creatine, protein, etc.)? Yes No
    If Yes then what substance? ___________________________

1

13.What is the lowest weight you have been at in the last year _____, highest _____? What is your ideal weight _______?

14. Do you have any trouble breathing or do you cough during or after practice? Yes No

15. Have you ever had heat cramps, heat illness, or muscle cramps? Yes No

16. Do you have any skin problems (itching, rashes, acne)? Yes No

Explain all "Yes" answers for questions 5 – 16: ____
____
____
____
____
____

17. Have you ever passed out during or after exercise?	Yes	No
Have you ever been dizzy during or after exercise?	Yes	No
Have you ever had chest pain during or after exercise?	Yes	No
Have you ever had high blood pressure?	Yes	No
Have you ever been told you have a heart murmur?	Yes	No
Have you ever had racing of you heart or a skipped heart beat?	Yes	No
Has anyone in your family died of heart problems or a sudden death before the age of 50?	Yes	No
Have you ever had high cholesterol	Yes	No
Have you ever had an EKG or echocardiogram?	Yes	No

Explain all "Yes" answers for question 17: ____
____
____
____
____

18. Have you ever sprained / strained, dislocated, fractured, or had repeated swelling or other injury of any bones or joints? Explain any "Yes" answers.

Head/Neck	Yes	No	____
Shoulder	Yes	No	____
Elbow & arm	Yes	No	____
Wrist, hand & fingers	Yes	No	____
Back	Yes	No	____
Hip / Thigh	Yes	No	____
Knee	Yes	No	____
Shin/Calf	Yes	No	____
Ankle, foot, toes	Yes	No	____

19. What is the average number of hours you sleep per night? ________________

20. What time do you usually go to sleep at night? And, what time do you usually wake-up in the morning? ________________ _

21. What time did you go to sleep last night and what time did you wake up this morning? ________________

Would you like to speak further to the principal investigator regarding any topics or concerns? (i.e., nutrition, supplements, drugs, heart problems, weight loss/gain, sexual diseases, concussions, etc.,)? Yes No
If yes then what topic? ________________________________ _____________

Please sign:
I hereby state that, to the best of my knowledge, my answers to the above questions are correct.

____
Athlete's Signature Date Signed

1

Appendix D: Physical Activity Questionnaire

Appendix A: Physical Activity Questionnaire

Think about all the exercise training in which you engage. Use that information to appropriately answer the following questions.

1. Have you competed before in strength competitions? If so, how often?

Yes or No If so, _______________ times/year

   a. If yes to #1: How long have you been training for strength competitions?

   _______________ years.

   b. If yes to #1: When you compete, which sport do you compete in (Powerlifting, Strongman, or Bodybuilding)?

   Event:_____________________________________

2. Are you currently engaged in a structured resistance-training program? If so, how long?

   Yes or No If so, _______________ years

3. How many hours of resistance training do you perform on average each week?

_______________ hours/week

4. How many times do you resistance train per week? Please indicate if you do more than once a day.

_______________ days/week Average_______________ times/day

5. How many times per week do you perform the following exercises?

   a. Barbell back squat: ________ times/week

   b. Barbell bench press: ________ times/week

6. How many years of experience do you have with following exercises? What is your estimated 1RM?

   a. Barbell back squat: __________ years; 1RM__________pounds

   b. Barbell bench press: __________ years; 1RM__________pounds

1. Please describe your average resistance training intensity based on your self-estimated maximum load.

_______________ % your maximum

2. Do you incorporate any aerobic training? If so, how many times per week?

Yes or No If so, _______________ times/week

3. Please describe your average aerobic training intensity on a scale below (as close as possible):

1 2 3 4 5 6 7 8 9 10

Very Light Light Moderate Intense Very Intense

4. Please best describe your occupation or daily activities other than your exercise training.

11. Do you have any coaching by a certified professional in general resistance training?

REFERENCES

1. Anderson, K and Behm, DG. Trunk muscle activity increases with unstable squat movements. *Can J Appl Physiol* 30: 33–45, 2005.

2. Barrett, K, Brooks, H, Boitano, S, and Barman, S. Ganong's Review of Medical Physiology Twenty-Third Edition. New York: McGraw Hill, 2010.

3. Bentley, JR, Amonette, WE, Witt, JKD, and Hagan, RD. Effects of different lifting cadences on ground reaction forces during the squat exercise. *J Strength Cond Res* 24: 1414–1420, 2010.

4. Bosco, C, Ito, A, Komi, P, Luhtanen, P, Rahkila, P, Rusko, H, et al. Neuromuscular function and mechanical efficiency of human leg extensor muscles during jumping exercises. *Acta Physiol Scand* 114: 543–550, 1982.

5. Bosco, C and Komi, P. Potentiation of the mechanical behavior of the human skeletal muscle through prestretching. *Acta Physiol Scand* 106: 467–72, 1979.

6. Bosco, C, Komi, P, and Ito, A. Prestretch potentiation of human skeletal muscle during ballistic movement. *Acta Physiol Scand* 111: 135–140, 1981.

7. Cavagna, GA, Dusman, B, and Margaria, R. Positive work done by a previously stretched muscle. *J Appl Physiol* 24: 21–32, 1968.

8. Chapman, D, Newton, M, Sacco, P, and Nosaka, K. Greater muscle damage induced by fast versus slow velocity eccentric exercise. *Int J Sports Med* 27: 591–598, 2006.

9. Comfort, P, Stewart, A, Bloom, L, and Clarkson, B. Relationships between strength, sprint, and jump performance in well-trained youth soccer players. *J Strength Cond Res* 28: 173–177, 2014.

10. Conceição, F, Fernandes, J, Lewis, M, Gonzaléz-Badillo, JJ, and Jimenéz-Reyes, P. Movement velocity as a measure of exercise intensity in three lower limb exercises. *J Sports Sci* 34: 1099–1106, 2016.

11. Cormie, P, McGuigan, MR, and Newton, RU. Adaptations in athletic performance after ballistic power versus strength training. *Med Sci Sports Exerc* 42: 1582–1598, 2010.

12. Earp, JE, Newton, RU, Cormie, P, and Blazevich, AJ. Faster movement speed results in greater tendon strain during the loaded squat exercise. *Front Physiol* 7, 2016.

13. Enoka, RM. Neuromechanical basis of kinesiology, 2nd ed. Champaign, IL, England: Human Kinetics Publishers, 1994.

14. Escamilla, RF, Fleisig, GS, Lowry, TM, Barrentine, SW, and Andrews, JR. A three-dimensional biomechanical analysis of the squat during varying stance widths. *Med Sci Sports Exerc* 33: 984–998, 2001.

15. 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.

16. Finni, T, Ikegawa, S, Lepola, V, and Komi, PV. Comparison of force-velocity relationships of vastus lateralis muscle in isokinetic and in stretch-shortening cycle exercises. *Acta Physiol Scand* 177: 483–491, 2003.

17. Fleck, SJ and Kraemer, WJ. Designing Resistance Training Programs. 2014.

18. González-Badillo, JJ and Sánchez-Medina, L. Movement velocity as a measure of loading intensity in resistance training. *Int J Sports Med* 31: 347–352, 2010.

19. Granata, KP and England, SA. Stability of dynamic trunk movement. *Spine (Phila Pa 1976)* 31, 2006.

20. Granata, KP and Marras, WS. The influence of trunk muscle coactivity on dynamic spinal loads. *Spine (Phila Pa 1976)* 20: 913–919, 1995.

21. Haff, GG and Triplett, NT. Essentials of Strength Training and Conditioning 4th Edition. Champaign, IL: Human Kinetics, 2015.

22. Hall, JE and Guyton, AC. Textbook of Medical Physiology. Philadelphia Pennsylvania: Elsevier Inc., 2006.

23. Hatfield, DL, Kraemer, WJ, Spiering, BA, Häkkinen, K, Volek, JS, Shimano, T, et al. The impact of velocity of movement on performance factors in resistance exercise. *J Strength Cond Res* 20: 760–766, 2006.

24. Helms, ER, Storey, A, Cross, MR, Brown, SR, Lenetsky, S, Ramsay, H, et al. RPE and velocity relationships for the back squat, bench press, and deadlift in powerlifters. *J Strength Cond Res* 31: 292–297, 2017.

25. IPF. International Powerlifting Federation Technical Rules Book. 2015.Available from: http://www.powerliftingipf.com/fileadmin/ipf/data/rules/technicalrules/english/2015_V2_IPF_Technical_Rules_Book_2015_classic_rules_in_back_section.pdf

26. Jackson, AS and Pollock, ML. Generalized equations for predicting body density of men. *Br J Nutr* 40: 497, 1978.

27. Jidovtseff, B, Harris, NK, Crielaard, JM, and Cronin, JB. Using the load-velocity relationship for 1RM prediction. *J Strength Cond Res* 25: 267–270, 2011.

28. Kilani, HA, Palmer, SS, Adrian, MJ, and Gapsis, JJ. Block of the stretch reflex of vastus lateralis during vertical jumps. *Hum Mov Sci* 8: 247–269, 1989.

29. Komi, P. Strength and Power in Sport (Encyclopaedia of Sports Medicine, Vol. 3). 2003.

30. Liow, DK and Hopkins, WG. Velocity specificity of weight training for kayak sprint performance. *Med Sci Sports Exerc* 35: 1232–1237, 2003.

31. Martins-Costa, HC, Diniz, RCR, Lima, FV, Machado, SC, De Almeida, RSV, De Andrade, AGP, et al. Longer repetition duration increases muscle activation and blood lactate response in matched resistance training protocols. *Motriz Rev Educ Fis* 22: 35–41, 2016.

32. Meylan, CMP, Nosaka, K, Green, JP, and Cronin, JB. Variability and influence of eccentric kinematics on unilateral vertical, horizontal, and lateral countermovement jump performance. *J Strength Cond Res* 24: 840–845, 2010.

33. Mike, JN, Cole, N, Herrera, C, Vandusseldorp, T, Kravitz, L, and Kerksick, CM. The effects of eccentric contraction duration on muscle strength, power production, vertical jump, and soreness. *J Strength Cond Res* 31: 773–786, 2017.

34. Moras, G, Rodriguez-Jimenez, S, Busquets, A, Tous-Fajardo, J, Pozzo, M, and Mujika, I. A metronome for controlling the mean velocity during the bench press exercise. *J Strength Cond Res* 23: 926–931, 2009.

35. Ormsbee, MJ, Carzoli, JP, Klemp, A, Allman, BR, Zourdos, MC, Kim, J-S, et al. Efficacy of the repetitions in reserve-based rating of perceived exertion for the bench press in experienced and novice benchers. *J Strength Cond Res* 1, 2017.

36. Palmitier, RA, An, KN, Scott, SG, and Chao, EYS. Kinetic chain exercise in knee rehabilitation. *Sport Med* 11: 402–413, 1991.

37. Piitulainen, H, Botter, A, Merletti, R, and Avela, J. Muscle fiber conduction velocity is more affected after eccentric than concentric exercise. *Eur J Appl Physiol* 111: 261–273, 2011.

38. Robergs, RA, Gordon, T, Reynolds, J, and Walker, TB. Energy expenditure during bench press and squat exercises. *J Strength Cond Res* 21: 123–130, 2007.

39. Roschel, H, Ugrinowistch, C, Barroso, R, Batista, M a B, Souza, EO, Aoki, MS, et al. Effect of eccentric exercise velocity on akt/mtor/p70(s6k) signaling in human skeletal muscle. *Appl Physiol Nutr Metab* 36: 283–290, 2011.

40. Sánchez-Medina, L and Gonzalez-Badillo, JJ. Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Med Sci Sport Exerc* 43: 1725–1734, 2011.

41. Sanchez-Medina, L, Perez, CE, and Gonzalez-Badillo, JJ. Importance of the propulsive phase in strength assessment. *Int J Sports Med* 31: 123–129, 2010.

42. Sato, K, Fortenbaugh, D, Hydock, DS, and Heise, GD. Comparison of back squat kinematics between barefoot and shoe conditions. *Int J Sports Sci Coach* 8: 571–578, 2013.

43. Siff, MC and Verkhoshansky, YV. Supertraining. In: Supertraining. 2009. p. 578

44. Stuart, MJ, Meglan, D a, Lutz, GE, Growney, ES, and An, KN. Comparison of intersegmental tibiofemoral joint forces and muscle activity during various closed kinetic chain exercises. *Am J Sports Med* 24: 792–799, 1996.

45. Svantesson, U, Grimby, G, and Thomee, R. Potentiation of concentric plantar flexion torque following eccentric and isometric muscle actions. *Acta Physiol Scand* 152: 287–293, 1994.

46. Tran, QT and Docherty, D. Dynamic training volume: A construct of both time under tension and volume load. *J Sport Sci Med* 5: 707–713, 2006.

47. Wilk, KE, Voight, ML, Keirns, MA, Gambetta, V, Andrews, JR, and Dillman, CJ. Stretch-shortening drills for the upper extremities: theory and clinical application. *J Orthop Sport Phys Ther* 17: 225–239, 1993.

48. Yack, HJ, Collins, CE, and Whieldon, TJ. Comparison of closed and open kinetic chain exercise in the anterior cruciate ligament-deficient knee. *Am J Sports Med* 21: 49–54, 1993.

49. Zourdos, MC, Jo, E, Khamoui, A V., Lee, SR, Park, BS, Ormsbee, MJ, et al. Modified daily undulating periodization model produces greater performance than a traditional configuration in powerlifters. *J Strength Cond Res* 30: 784–791, 2016.

50. Zourdos, MC, Klemp, A, Dolan, C, Quiles, JM, Schau, KA, Jo, E, et al. Novel resistance training-specific rating of perceived exertion scale measuring repetitions in reserve. *J Strength Cond Res* 30: 267–275, 2016.