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The Influence of Strength in Load-Velocity Relationships in the Back Squat

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The Influence of Strength in Load-Velocity Relationships in the Back Squat

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A dissertation

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in partial fulfillment

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Doctor of Philosophy in Sport Physiology and Performance

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by

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ABSTRACT

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Load-velocity relationships may vary between people of different strength levels and across different loads. The purpose of this dissertation was to investigate how external loads influence the velocity characteristics of the back squat exercise, and the influence of strength on these variables. Healthy male students with a history of resistance training completed repetitions at specified intensities of their estimated one-repetition maximum (1RM) until they reached 1RM. Back squat 3D motion analysis was captured using four Vicon T010 cameras (Vicon Motion Systems Ltd.; Oxford, UK) and Vicon Nexus 1.8.5 software. Data were transported into R custom coding statistical analysis software (version 3.5.2; The R Foundation) to calculate velocity analyses which determined mean and peak concentric (MCV, PCV) and eccentric (MEV, PEV) values. Participants were grouped by their relative strength (body mass/1RM) in the back squat, as well as their ability to move often prescribed loads with greater speed (63-70%1RM, 83-87%1RM). Between-groups comparisons were made for MCV at all loading conditions, and correlational relationships between all velocity measures (MEV, PEV, MCV, PCV) were examined for each group. For all subjects, there was a significant effect for relative intensity (%1RM) on MCV, but only for the groups organized by MCV at 63-70%1RM and 83-87%1RM was there a between-subjects effect for group. Correlational analyses between velocity measurements during concentric and eccentric phase of the back squat showed a tendency for high relationships ($r = 0.5$-0.69) between all phases that weakened as the relative intensity increased. These differences were illustrated uniquely between subject grouping conditions. These results indicate that load-velocity characteristics of the back squat cannot necessarily be positively related to strength level in the movement, and that profiling athletes by their velocities at specific relative intensities could be an effective means of organization.

DEDICATION

I dedicate this work to my parents, James C. and Eve W. Light, and my wife, Kristen. I'll never be able to fully express my gratitude for the love and support they've given me throughout this process.

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I’d like to thank Dr. Kimi Sato for all his help and encouragement. I owe a lot of my progress to his ability to work quickly and efficiently, and to shove me in the right direction.

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TABLE OF CONTENTS

Page

Chapter

2. REVIEW OF THE LITERATURE

3. STUDY 1: LOAD-VELOCITY RELATIONSHIPS IN THE BACK SQUAT: THE INFLUENCE OF RELATIVE STRENGTH

4. STUDY 2: THE RELATIONSHIPS BETWEEN THE VELOCITIES OF THE ECCENTRIC AND CONCENTRIC PHASES OF THE BACK SQUAT

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

For the strength and conditioning coach interested in providing their athletes with the most effective service, the translation of research into practice is a top priority. This dissertation was undertaken with the coach in mind; the problems within were investigated in order to provide information useful in the field.

A current issue in the world of sport performance is the development and proliferation of wireless technology used to measure velocity during resistance training. The scientific community attempts to keep up with these new developments, to validate devices and give suggestions for their best use. Already, much work has been done to guide strength and conditioning professionals in their use of velocity measurements, including using them as a method for 1RM prediction (Banyard, Nosaka, & Haff, 2017; Jidovtseff et al., 2011; Jovanović & Flanagan, 2014; Picerno et al., 2016), fatigue identification (Sanchez-Medina & Gonzalez-Badillo, 2011), and the monitoring and prescription of training loads (Banyard, Nosaka, & Haff, 2017; González-Badillo & Sánchez-Medina, 2010; Jovanović & Flanagan, 2014; Mann, Ivey, & Sayers, 2015; Sato et al., 2018).

Though these types of investigations have helped to provide valuable insight to the nature of load-velocity relationships, certain questions remain unanswered. Much of a strength and conditioning coach's job is concerned with structural details, such as program design and monitoring, and research into this area has proven valuable. However, velocity measurement may be able to provide more insight into more nuanced aspects of athlete development. For example, it may help to reveal how strength and movement velocity interact and if this is demonstrated differently across individuals or with different external loads. Velocity during different phases of an exercise could show an interrelationship that better helps a coach to explain and teach technique to their athletes, as well as deepen their own understanding of it, thus broadening their coaching tools and knowledge. These ideas were targeted for investigation in this dissertation.

In Study 1, the purpose was to examine the role of strength in load-velocity relationships. Specifically, there was an interest in load-velocity relationships and how they were expressed differently between weak and strong participants, but also between those who were able to move faster at certain working loads. Study 2 was done with focus on the velocities of phases of an exercise and their relationship to each other, and if they were affected by the lifter's strength or propensity to move faster at a certain resistance.

CHAPTER 2
REVIEW OF LITERATURE

Introduction

Technology has advanced rapidly over the last two decades, allowing both coaches and fitness enthusiasts easier access to data that was previously unobtainable outside a laboratory setting. Private industry has stepped in to take advantage of the interest in this data, and many new devices have been created and marketed to coaches, as well as the general public. An area of study which has become a major focus of private sports technology companies is that of velocity, specifically barbell velocity as it relates to resistance training prescription and performance.

Velocity is of particular interest because of its relation to the basic power equation (Power = force x velocity). As it is expressed here, power is the product of external force and the velocity of an object in the direction the force is exerted. Power may be the most important factor in athletics, as the athlete who accomplishes the given work quicker is most likely to win (Stone, Stone & Sands, 2007).

The Force-Velocity Curve

The relationship of force and velocity is best recognized by the hyperbolic curve first described by A. V. Hill (1953). This curve implies that the velocity of the muscular contraction is dependent upon the load which it is acting against – high loads being moved at lower velocity while lower loads will be moved at a higher velocity. This, while initially asserted with respect to isolated muscles, has been demonstrated with various resistance training exercises, including the back squat (Banyard, Nosaka, & Haff, 2017; Bazuelo-Ruiz et al., 2015; Cronin, Mcnair, & Marshall, 2003; González-Badillo & Sánchez-Medina, 2010; Goodin, 2015; Jidovtseff, Harris, Crielaard, & Cronin, 2011; Jovanović & Flanagan, 2014; Pareja-Blanco et al., 2014; Picerno et al., 2016; Suchomel & Sole, 2017; Zink et al., 2006).

The Back Squat

The squatting movement is viewed as a fundamental movement skill. Proficiency in it is greatly beneficial to children and adolescents in order to master optimal movement strategies during growth and development (Kushner et al., 2015; Lubans et al., 2010). The back squat, named for the position of the barbell relative to the body, is a foundational movement in strength and conditioning for sport performance. Mastery of the lift is extremely important, and has been recommended both as a prerequisite to heavy resistance training as well as a movement screening assessment (Myer et al., 2014; Myer et al., 2011).

The basic description of the back squat is simple. The lifter stands in a fully upright position with the barbell supported on their trapezius or posterior deltoids, descends until a point where their thighs are parallel to the ground and their hips slightly below their knees, then returns to the standing position (Myer et al., 2014; Schoenfeld, 2010). However, within this framework exists many variations, load placement and stance width being the most notable. The barbell can be placed in either a “high-bar” or “low-bar” position. The high-bar position is when the barbell is supported on the upper trapezius, sitting slightly above the acromion. The low-bar position sees the barbell situated slightly below the acromion, resting on the posterior deltoid (Schoenfeld, 2010). A stance width of approximately shoulder-width apart if generally recommended, but varies with the training goal or individual preference (Comfort, McMahon, & Suchomel, 2018). Athletes competing in the sport of Powerlifting tend to favor a low-bar load placement and wide stance widths (Swinton et al., 2012).

The use of the back squat is widespread throughout the sporting world and rehabilitation settings as a means to enhance lower body strength (Comfort et al., 2018; Ecamilla, 2001; Ebben & Blackard, 2001). It has even been proposed as a standard assessment of performance-limiting factors such as limited mobility or strength deficits (Myer et al., 2014). Strength in the back squat has been correlated with performance in many sporting tasks, especially those requiring high power outputs such as jumping and sprinting (Comfort, McMahon, & Suchomel, 2018; Suchomel, Nimphius & Stone, 2016; Chelly et al., 2009; Wisloff et al., 2004).

Force-Velocity Measures and their Impact on Resistance Training

In preparation for tasks involving varied levels of power output for an athlete, the force-velocity curve is a primary concern for a strength and conditioning professional. It has been shown that training with different loads can alter the shape of the force-velocity curve (Zatsiorsky & Kraemer, 2006; Verkhoshanksy & Siff, 2009, Stone, Stone & Sands, 2007). For example, training with heavier loads in an explosive manner ("strength-speed" training) may result in the ability to produce higher forces with higher velocities or training with lighter loads at higher velocities ("speed-strength" training) may allow for increased velocity at lower levels of force production (Zatsiorsky & Kraemer, 2006; Verkhoshanksy & Siff, 2009).

Building on that idea, it has been asserted that athletes should train across a range of loads in order to enhance the development of their overall force-velocity profile (Haff & Nimphius, 2012; Suchomel et al., 2017). This can be accomplished by managing variables such as the prescribed load, but also through exercise selection if the force-velocity characteristics are known. Figure one below shows a theoretical example of this in which weightlifting derivatives are plotted along the curve signifying the force-velocity relationship of various movements (Suchomel et al., 2017).

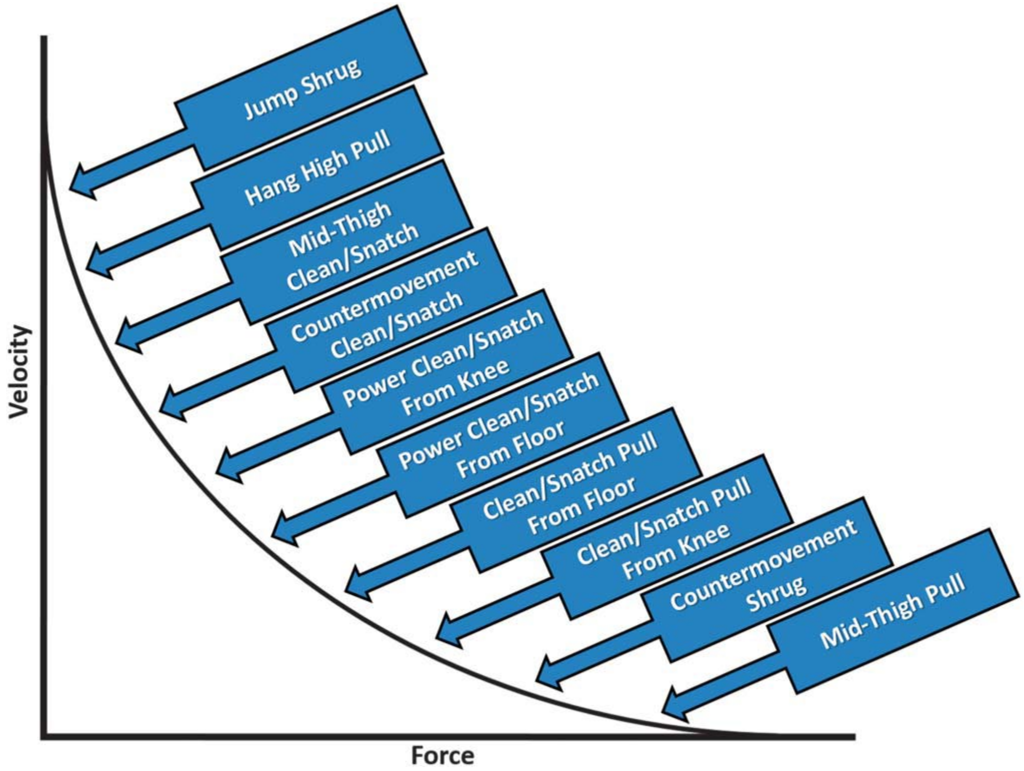

Figure 2.1. Force-velocity curve with respect to weightlifting derivatives. Used with permission from Suchomel et al., 2017, *Strength and Conditioning Journal, 39*, p.11.

Identifying and classifying exercises and the proper loading parameters for them in this way may help to advance training prescription, making it easier for coaches to assign exercises and loads specific to the sporting task to be performed.

The force-velocity curve and its potential for change are widely known in the sport science and strength and conditioning communities. However, it has not yet been conclusively demonstrated to be of consistent shape throughout all athletic populations. This could be of particular interest to sport scientists and coaches in order to help create a more complete profile of the athletes in a given sport.

Recently, considerable interest has been paid to the interaction between eccentric and concentric phases of resistance exercise, particularly with an altered eccentric phase either through duration or overload (Munger et al., 2017; Wagle et al., 2018, 2017; Wagle et al., 2018). In these studies; however, the emphasis has largely been on the effect of the eccentric portion of the lift on the completion of the concentric, not the direct comparison of the two across different loading parameters. This comparison may produce valuable insights into the nature of their relationship to each other across a range of loads, especially when done with a diverse population, in terms of strength level and training experience. The inability to generate high eccentric forces could not only compromise the concentric movement phase, but also illustrate a lessened ability to negotiate eccentric forces on the field of play (Stone, Stone & Sands, 2007).

In addition to the possible influence of eccentric force and velocity characteristics on those of the concentric, there may exist an impact on the “sticking region” of the concentric portion of the back squat. This can be defined as the portion of the concentric phase of the lift between the area of the initial maximal upwards velocity to the first local minimum of the upwards velocity of the barbell (Madsen and McLaughlin, 1984; van den Tillaar et al., 2014). There are a number of factors that can impact how and when this region will present itself, the most common being relative load (%1RM) and level of fatigue (Newton et al., 1997; van den Tillaar et al., 2014). It is reasonable to speculate that subjects who are weak in the back squat would exhibit this region under different circumstances (relative load conditions) than those who are strong, and possibly different compensatory strategies may also exist between them, such as altered patterns of horizonal barbell displacement. Examining this in detail could help researchers as well as strength coaches who are interested in the topic in both their understanding and monitoring of the back squat.

Velocity and Wireless Technology in Sport

Advancements in wireless sport technology in recent years continue to make velocity and acceleration data that was once possible to obtain only in the laboratory setting widely available. Though the purchase of some of these systems can be cost prohibitive for the recreational athlete or average consumer, college and professional sports organizations with the available funds can now easily amass physiological and performance data that was once impossible outside the lab. Beginning with Global Positioning System (GPS) technology and extending into commercial accelerometry, options for measuring velocity are rapidly expanding.

GPS Technology in Sport

Beginning with commercially available GPS technology and its first attempted validation for sport application in 1997 (Shultz & Chambaz, 1997), technology has rapidly been developed in the private sector to meet the demand for tracking locomotive (walk, run, sprint) velocity. Currently it is quite common for recreational athletes and fitness enthusiasts, particularly distance runners who are interested in distance and pacing/running velocity data, to track their training with the use of wearable GPS technology. However, this widespread as easy use of GPS is a relatively recent phenomenon. Early use of GPS technology was often impractical due to a cumbersome receiver and the deliberate degradation of satellite transmission accuracy by the United States Department of Defense until May 2000 (Terrier et al., 2000).

GPS technology has now become widely used in sport as a means of monitoring training and performance specific to kinematic measures. The most common measure is of time-motion analysis, which is descriptive of a player's movements on the field and can be used to create an activity profile for that athlete (Aughey, 2011). A common feature of this is a figure representing the total distance an athlete has moved, as well as a number of accelerations and decelerations performed. Performance data are often further broken down into zones of speed and impact in order to show how much time was spent or how much distance an athlete covered while at different levels of intensity (Cummins et al., 2013).

However, due to the low sampling frequency of GPS technologies, 10 Hz at most, reliability is reduced for activities requiring regular changes of direction and brief, intense accelerations (Coutts & Duffield, 2010; Rampinini et al., 2015). In general, the higher the velocity of the movement, the lower the reliability of GPS (Aughey, 2011). This is especially true of shorter distances traveled. Variability and error in GPS measurements have been shown to be consistently higher in tasks with shorter distances versus longer ones, or tasks of the same distance performed at a faster velocity when compared to slower (Augey, 2011; Peterson et al., 2009; Jennings et al., 2010; Portas et al., 2010).

For this reason, GPS measured distances and velocities are generally more valid the longer the duration of the task. This makes them far better suited to the needs of endurance athletes or to sport scientists aiming to measure distances and average velocities over the course of an entire field sport practice session or competitive event. For explosive actions of brief duration, such as resistance training, other means of velocity measurement must be used to ensure accurate measurements are being taken.

Velocity Measurement in Resistance Training

In the last decade, devices for measuring velocity specifically in strength and conditioning have become more popular as new data collection technology as become available (Balsalobre-Fernandez et al., 2017; Sato et al., 2018). It is no longer necessary for a coach to take his or her team into a laboratory setting in order to obtain velocity measures that could be used in performance testing or monitoring.

Methods of measuring velocity outside the laboratory began with the introduction of commercially available tethered linear position transducers (LPT) such as the Tendo Power Output Unit (Tendo Sports Machines; Trencin, Slovak Republic), which has been validated as the "Fitro-Dyne" by Jennings et al. (2005). The GymAware (GymAware Power Tool; Kinetic Performance Technologies, Canberra, Australia) was validated later by Drinkwater et al. (2007). Both of these LPT have consistently been shown through research to be accurate and reliable (Garnacho-Castaño, López-Lastra, & Maté-Muñoz, 2015; Banyard, Nosaka, Sato, & Haff, 2017). Following this was the development and subsequent commercial availability of wireless accelerometry devices such as the Myotest (Myotest SA; Sion, Sweden), which was validated in the early 2010's (Casatelli, Muller, & Maffiuletti, 2010; Comstock et al., 2011). More recently, starting in 2014, devices utilizing Bluetooth technology like the PUSH band (PUSH Inc.; Toronto, Canada), Beast sensor (Beast Technologies; Brescia, Italy), and the BarSensei (Assess2Perform; Montrose, Colorado, USA) have emerged.

The specific variables measured by portable devices can vary, with some calculating estimations of power in addition to peak and mean velocity and displacement. Reliability and validity for these devices may vary between not only the specific measurements, but also between measurements at different loading conditions (Banyard et al. 2017). In general, it has been recommended that mean velocity be used for monitoring training applications, as it is easily collected from most LPTs and wireless devices (Garcia-Ramos et al., 2017).

These smaller and more portable wireless units have been marketed not only to fitness enthusiasts, but also to professional and collegiate team sports organizations as a method of collecting resistance training velocities without the supposed hassle of using a stationary, tethered LPT. Many, including elite professional and college athletic programs, have invested in this technology as interest in training velocity has increased in recent years (Mann, Ivey & Sayers, 2015).

Velocity-Based Training (VBT)

Evidence of the specificity of training velocity and its impact on performance have been known for years, first being reported by Moffroid & Whipple (1970). Further work demonstrated the importance of velocity in exercise selection and loading for power production (Wilson, 1993; Baker, 1995; Baker & Newton, 2005; Baker, 2007). Velocity is extremely important in the training process, and has become easier to measure as technology advances. As accessibility to the relevant technology has increases, so also have research opportunities to seek practical applications for the data (Behm & Sale, 1993; Sato et al., 2018). For example, load-velocity relationships have been used as a method for 1RM prediction (Banyard, Nosaka, & Haff, 2017; Jidovtseff et al., 2011; Jovanović & Flanagan, 2014; Picerno et al., 2016), and fatigue identification (Sanchez-Medina & Gonzalez-Badillo, 2011).

In the practical setting, the adoption of wireless technology for use in velocity-based training (VBT) could serve as a viable alternative to the typical method of monitoring training volume (Sets x Repetitions x Load). Currently available wireless devices such as the Beast sensor, PUSH, and BarSensei can instantly calculate all these data as well as velocity and displacement measures through their associated smartphone or tablet applications and organize it for the strength coach during the training session. This could represent a coach-friendly tool that would collect a large amount of useful data without the hassle of the wires and lengthy data processing sometimes associated with LPTs (Sato et al., 2015).

The monitoring and prescription of training loads and intensities based on velocity has emerged as a reliable practice (Banyard, Nosaka, & Haff, 2017; González-Badillo & Sánchez-Medina, 2010; Jovanović & Flanagan, 2014; Mann, Ivey, & Sayers, 2015; Sato et al., 2018). Training intensity for resistance exercise is typically prescribed either in terms of relative intensity as a percentage of a one repetition maximum (%1RM) or a set-repetition best (3x5, 3x10, etc.). However, basing training prescriptions off of a one-time direct assessment may not accommodate continuous advancement in that athlete's strength-power development or their fluctuations in performance based on outside stressors (Mann et al., 2015; Fry & Kraemer, 1997). Velocity measures have been found to have a very close, linear relationship with relative intensity (%1RM) (González-Badillo & Sánchez-Medina, 2010; González-Badillo, Marques, & Sánchez-Medina, 2011), and can be used as a way of assessing if the load prescription is appropriate to the training goal. For example, if the training goal is for high power outputs and the movement is too slow, then the coach simply has to decrease the load slightly. A recent comparison between VBT and traditional relative loading (%1RM) showed similarly enhanced strength levels, but a significant increase in countermovement jump only for the VBT group (Dorrell, Smith, & Gee, 2019). Interestingly, the VBT group was able to accomplish this with significantly less total training volume than the %1RM group (Dorrell et al., 2019).

Furthermore, VBT may help to further individualize training in ways which could result in increased efficacy. Monitoring of an athlete’s training velocities at various working loads gives a coach the chance to customize prescription and track changes in that athlete’s progress over time across a range of velocity demands (Jovanović & Flanagan, 2014). It may be that this ability to individualize training will emerge as the primary benefit to VBT due differences between athletes in the ability to express velocity in given movements, which may be further influenced by experiential or anthropometric factors (Jovanović & Flanagan, 2014; Zourdos et al., 2016; Fahs, Blumkaitis & Rossow, 2019). Different resistance training exercises have been found to have significantly different velocity characteristics through their relative loading spectrums (Fahs et al., 2019), and researchers have also found differences in velocity across loading conditions based on sex (Askow et al., 2018). Though velocity ranges have been recommended for certain training goals, such as 0.3-0.45 m/s mean concentric velocity for maximum strength (Mann, 2013), such blanket recommendations may be problematic and may vary (Mann et al., 2015; Spitz et al., 2019).

VBT has wide-ranging potential application. Research has demonstrated it to be an effective method of prescribing and monitoring training, as well as determining fatigue and changes in maximal strength. As VBT, and the availability of technology by which to secure and analyze the data needed to perform it, becomes more popular and widespread, there comes the need for further and deeper investigation through research.

CHAPTER 3: LOAD-VELOCITY RELATIONSHIPS IN THE BACK SQUAT: THE INFLUENCE OF RELATIVE STRENGTH

ABSTRACT

by

Thaddeus J. Light

Squat load-velocity relationships may be influenced by a person's base strength level or their propensity to move certain ranges of relative loads at higher concentric velocities. PURPOSE: To investigate the influence of relative strength levels on load-velocity relationships in the back squat. METHODS: Healthy male participants (N=18) experienced in the back squat performed repetitions at regular relative intensity (%1RM) intervals of their estimated one-repetition maximum (1RM). Participants were then grouped according to relative strength (1RM/body mass), as well as mean concentric velocity (MCV) at commonly prescribed levels of relative intensity (63-70%1RM, 83-87%1RM). A series of 2x8 (group by relative intensity) repeated-measures analysis of variance (ANOVA) was performed to identify group effects on MCV over all relative intensities. RESULTS: A significant within-subjects effect was shown for all group comparisons: weak vs. strong [$F(2.973,57.568) = 298.604$, $p < 0.001$]; fast vs. slow at 63-70%1RM [$F(2.888,46.212) = 290.853$, $p < 0.001$]; fast vs. slow at 83-87%1RM [$F(2.867,45.868) = 303.078$, $p < 0.001$]. There was a statistically significant between subjects main effect was for fast vs. slow at 83-87%1RM [$F(1,16) = 8.758$, $p = 0.009$] and 63-67%1RM [$F(1,16) = 12.315$, $p = 0.003$]. DISCUSSION: Contrary to what was hypothesized, weaker participants tended to perform at higher velocities across all loading conditions. Sorted by relative strength alone (Weak vs. Strong participant groups), the stronger group performed their squats at a slower MCV at all loading conditions. Similarly, when the participants were regrouped based on their MCVs at 63-70% and 83-87% 1RM, the faster group in each case was weaker in terms of mean relative strength. More research into the influence of strength on load-velocity relationships is needed.

Keywords: Back Squat, Velocity, Strength, Load-Velocity Relationships, Concentric Velocity

INTRODUCTION

The back squat is widely used by strength and conditioning professionals in order to help prepare their athletes for sport. It is regarded as one of the most important lifts in training by coaches at all levels in order to help build lower body strength and power (Ebben and Blackard, 2001). Power may be the most important factor in athletics, as the athlete who accomplishes the given work quicker is most likely to win (Stone, Stone & Sands, 2007).

Velocity is of particular interest because of its relation to the basic power equation (P = force x velocity). As it is expressed here, power is the product of external force and the velocity of an object in the direction the force is exerted. The relationship of force and velocity is best recognized by the hyperbolic curve first described by A. V. Hill (1953). This curve implies that the velocity of the muscular contraction is dependent upon the load which it is acting against – high loads being moved at lower velocity while lower loads will be moved at a higher velocity. This, while initially asserted with respect to isolated muscles, has been demonstrated with various resistance training exercises, including the back squat (Banyard, Nosaka, & Haff, 2017; Bazuelo-Ruiz et al., 2015; Cronin, McNair, & Marshall, 2003; González-Badillo & Sánchez-Medina, 2010; Goodin, 2015.; Jidovtseff et al., 2011; Jovanović & Flanagan, 2014; Pareja-Blanco et al., 2014; Picerno et al., 2016; Suchomel & Sole, 2017; Zink et al., 2006).

More recently, devices for specifically measuring velocity in strength and conditioning have become more popular as new data collection technology as become available (Balsalobre-Fernandez et al., 2017; Sato et al., 2018). Though evidence of the specificity of training velocity and its impact on performance have been known for years, first being reported by Moffroid & Whipple (1970), greater accessibility to the relevant technology has created research opportunities to seek practical applications for the data (Behm & Sale, 1993; Sato et al., 2018). For example, load-velocity relationships have been used as a method for 1RM prediction (Banyard, Nosaka, & Haff, 2017; Jidovtseff et al., 2011; Jovanović & Flanagan, 2014; Picerno et al., 2016), fatigue identification (Sanchez-Medina & Gonzalez-Badillo, 2011), and the monitoring and prescription of training loads (Banyard, Nosaka, & Haff, 2017; González-Badillo & Sánchez-Medina, 2010; Jovanović & Flanagan, 2014; Mann, Ivey, & Sayers, 2015; Sato et al., 2018).

The use of these data by strength and conditioning professionals to better inform training prescription and athlete profiling could be beneficial. For this reason, the factors that influence velocity across a wide variety of loads needs to be investigated. The primary purpose of this study was to examine differences in back squat mean concentric velocity (MCV) across a range of relative loads (%1RM) for individuals of different strength levels. A secondary goal of the study was to investigate whether individuals' velocities in commonly prescribed loads could be used as a method of athlete profiling to aid in the organization of training for strength and conditioning coaches.

METHODS

Participants

Eighteen male (N=18) students experienced in resistance training were recruited for this study. In order to meet the inclusion criteria for the study, all participants had to be at least 18 years of age, free of musculoskeletal injury, participating in weight training for at six months, and familiar with the back squat exercise.

Participants reported to the lab where they first read and signed a written informed consent document approved by the East Tennessee State University Institutional Review Board. After reviewing and signing the informed consent document, the participants were asked to complete a pre-participation survey in order to ensure that they met the inclusion criteria for the study. Following the survey, the participant's height and weight were taken and they were asked to give an estimate of their back squat 1RM.

Table 3.1 Participant Data (N=18)

	Age	Training Age (yrs)	Height (cm)	Body Mass (kg)	1RM/BM	1RM
Mean	26.11	7.10	176.46	90.97	1.74	159.50
SD	5.76	6.41	6.41	9.75	0.29	36.17

Procedures

Upon completion of the pre-participation screening, the participants entered the lab to begin testing procedures (see table 3.2).

Table 3.2 Testing Procedures

General Warm-up:	
25 Jumping Jacks	
10 Bodyweight Squats	
Dynamic Stretching	
Back Squat Testing	
%Estimated 1RM	Repetitions
20%	2
30%	2
40%	2
50%	2
60%	2
70%	2
75%	1
80%	1
85%	1
90%	1
95%	1
100%	1

Mean velocity calculated for all variables at relative loads involving two repetitions. Participants were instructed to complete the repetitions explosively, in order to ensure better accuracy in the load-velocity relationships.

If the participants' 1RM was underestimated, they were asked to continue moving up in weight at 5% increments of their estimated 1RM (105%, 110%, etc.) until they were judged to have reached their maximum weight or failed an attempt. Failure was defined as the participant not reaching a depth at which their thighs were parallel to the floor, or the inability to complete the concentric portion of the repetition. The participants' heaviest completed repetition was counted at their 1RM (100%) and relative percentages for all other loads lifted were recalculated based on this. From this recalculation, the repetitions were organized into groups representing similar percentage ranges of 1RM.

Once the data collection was completed, participant groups were formed in three ways: 1. Relative strength (1RM/body mass) (weak n=10, strong n=8), 2. MCV at a moderate load (slow m=11, fast n=7), and 3. MCV at a heavy load (slow n=10, fast n=8) (see tables 3.3, 3.4, & 3.5). Group composition was determined by dividing participants at the 50th percentile for the above-mentioned variables. For the moderate and heavy load used to reorganize participant groups, the ranges of 63-70%1RM and 83-87%1RM were chosen, respectively. These ranges represent commonly prescribed loads by strength and conditioning professionals.

Table 3.3 Participant Group Data - Weak vs. Strong

			Weak (n=10)			
	Age (yrs)	Training Age (yrs)	Height (cm)	Body Mass (kg)	1RM (kg)	1RM/BM
Mean	26.10	6.20	175.56	89.67	139.50	1.55
SD	5.57	6.35	6.69	10.20	27.24	0.21
CV	21.33	102.45	3.81	11.38	19.52	13.34
			Strong (n=8)			
	Age (yrs)	Training Age (yrs)	Height (cm)	Body Mass (kg)	1RM (kg)	1RM/BM
Mean	26.13	8.22	177.59	92.59	184.50	1.98
SD	6.38	6.73	6.30	9.58	30.62	0.16
CV	24.42	81.90	3.55	10.35	16.59	8.20

Table 3.4 Participant Group Data - Differentiated by MCV at 63-70% 1RM

Slower Group (n=11)

	Load at 63-70% (kg)	Age (yrs)	Training Age (yrs)	Height (cm)	1RM (kg)	Body Mass (kg)	1RM/BM
Mean	112.36	26.00	7.70	176.26	168.36	91.52	1.84
SD	12.40	6.23	6.67	6.47	21.71	8.79	0.15
CV	11.04	23.96	86.59	3.67	12.89	9.61	8.19

Faster Group (n=7)

	Load at 63-70% (kg)	Age (yrs)	Training Age (yrs)	Height (cm)	1RM (kg)	Body Mass (kg)	1RM/BM
Mean	98.86	26.29	6.14	176.77	145.57	90.10	1.59
SD	29.86	5.41	6.36	6.81	50.50	11.80	0.39
CV	30.21	20.57	103.57	3.85	34.69	13.09	24.60

Table 3.5 Participant Group Data - Differentiated by MCV at 83-87% 1RM

Slower Group (n=10)

	Load at 83-87% (kg)	Age (yrs)	Training Age (yrs)	Height (cm)	1RM	Body Mass (kg)	1RM/BM
Mean	141.00	26.10	7.98	176.21	165.90	90.84	1.83
SD	17.44	6.56	6.97	6.82	21.20	8.96	0.15
CV	12.37	25.12	87.38	3.87	12.78	9.87	8.36

Faster Group (n=8)

	Load at 83-87% (kg)	Age (yrs)	Training Age (yrs)	Height (cm)	1RM	Body Mass (kg)	1RM/BM
Mean	128.38	26.13	6.00	176.78	151.50	91.13	1.63
SD	41.42	5.03	5.90	6.30	49.67	11.30	0.39
CV	32.27	19.24	98.40	3.57	32.79	12.40	23.57

Instrumentation

A combination scale and stadiometer was used to measure the participants' height and weight. Back squat 3D motion analysis was captured using four Vicon T010 cameras (Vicon Motion Systems Ltd.; Oxford, UK) and Vicon Nexus 1.8.5 software (see Figure 3.1 – recording diagram). Velocity analyses determined mean concentric (MCV) values. Data were transported into R custom coding statistical analysis software (version 3.5.2; The R Foundation) to calculate the dependent variable listed above.

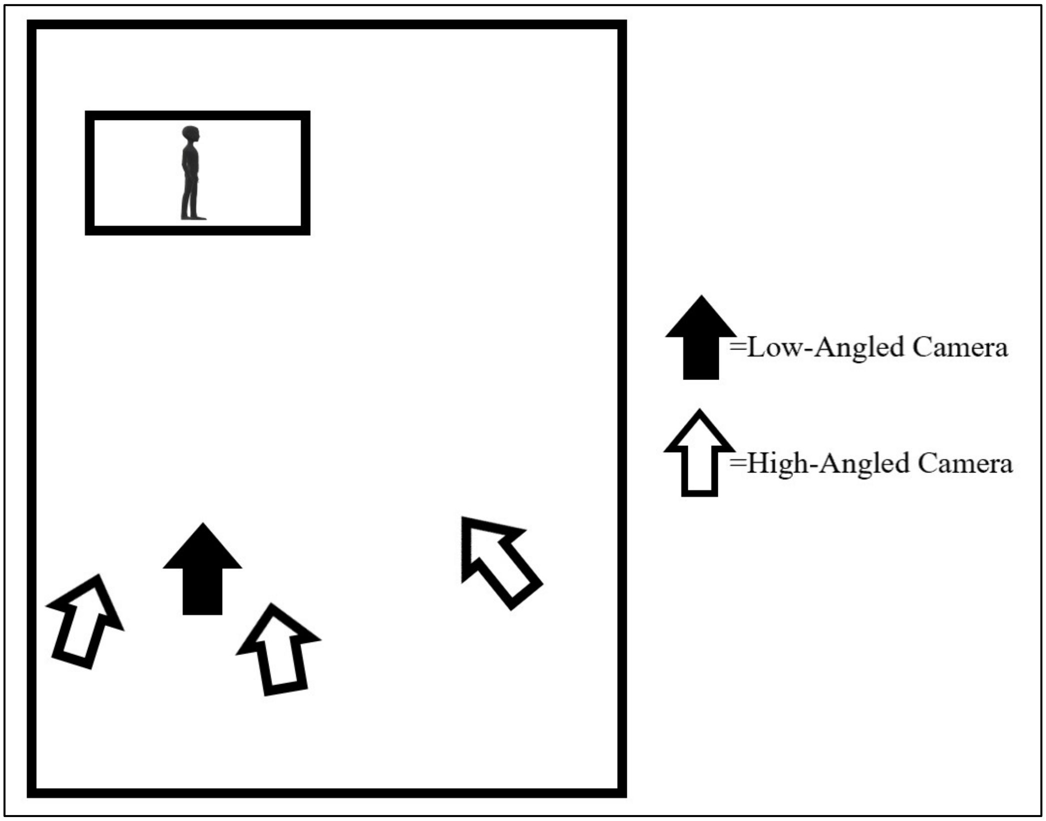

Figure 3.1 VICON Camera Positions

Statistical Analyses

Participant group MCV means, standard deviations (SD), and coefficients of variation (CV) were determined for all relative load conditions. Cohen's *d* was used for effect size to investigate the degree of difference between participant groupings based on group member relative strength, as well as the practical speed difference between groups at all loading conditions. The scale used to determine the magnitude of effect size – Small (0.25), Moderate (0.5), Large (1.0) – was in accordance with Rhea (2004) and his suggested scale for highly trained athletes, those who had been involved in training for at least five years. A series of 2x8 (group by relative intensity) repeated measures analysis of variance (ANOVA) was performed to identify group effects on MCV over all relative intensities. A Greenhouse-Geisser correction for sphericity was applied to these results for within-subject effects. A series of one-way ANOVAs followed by a Bonferroni post-hoc test was used to examine differences between mean values for MCV at each loading condition for all groups individually.

RESULTS

Effect Size

Calculations for Cohen's *d* to investigate group differences based on relative strength showed a large effect for Weak/Strong group (2.35), and a moderate effect for both the Fast/Slow groups at 63-70%1RM (0.85) and 83-87%1RM (0.66) (see table 3.6). Results indicate a moderate practical effect by which weaker people are faster in MCV.

Table 3.6 Effect size between groups (Cohen's d*)*

Grouping Criteria	**Groups**	**Mean 1RM/BM**	**SD**	**Effect Size (Cohen's *d*)**
Relative Strength	Weak	1.56	0.20	2.35†
	Strong	1.98	0.16	
MCV at 63-70%1RM	Slower	1.84	0.15	0.85^{x}
	Faster	1.59	0.39	
MCV at 83-87%1RM	Slower	1.83	0.15	0.66^{x}
	Faster	1.63	0.39	

†=Large effect, ^{x}=Moderate effect, Rhea (2004)

Group Comparisons

For comparison of groups based on relative strength, a 2x8 repeated measures ANOVA showed a significant within-subjects effect for relative intensity on MCV for all loading conditions [$F(2.973,57.568) = 298.604$, $p < 0.001$]; however, Levene's test showed significant variance at 100% 1RM, indicating the variance for MCV at 100% 1RM was not homogenous. A statistically nonsignificant interaction effect was observed between groups and relative intensity [$F(2.973,47.568) = .725$, $p = 0.541$]. The between-subjects group effect was found to be nearly significant statistically [$F(1,16) = 3.212$, $p = 0.092$].

When comparing of groups based on participant MCV at 63-70%1RM, a 2x8 repeated measures ANOVA showed a significant within-subjects effect for relative intensity on MCV for all loading conditions [$F(2.888,46.212) = 290.853$, $p < 0.001$]. The interaction effect between groups and relative intensity was found to be nonsignificant [$F(2.888,46.212) = 0.880$, $p = 0.455$]. A significant between-subjects effect was demonstrated for group [$F(1,16) = 12.315$, $p = 0.003$].

Participants groups based on MCV at 83-87%1RM, when compared across loads with a 2x8 repeated measures ANOVA showed a significant within-subjects effect for relative intensity on MCV [$F(2.867,45.868) = 303.078$, $p < 0.001$]. Group-relative intensity interaction effect was found to be nonsignificant [$F(2.867,45.868) = 0.937$, $p = 0.427$]. A significant between-subjects effect was demonstrated for group [$F(1,16) = 8.758$, $p = 0.009$].

For all participant grouping conditions, a Greenhouse-Geisser correction for sphericity was applied when interpreting the test results for within-subject effects.

Group Load-Velocity Relationships

For each participant group, a one-way ANOVA with a Bonferroni post-hoc analysis was performed to investigate differences in MCV between all loading conditions. Significant differences were found for MCV for all groups (see table 3.7).

Table 3.7 One-way Analysis of Variance for Group MCV

Participant Group	*df*	*F*	*p*
Weak (n=10)	7, 72	69.168	<.001
Strong (n=8)	7, 56	65.144	<.001
Fast at 63-70% (n=11)	7, 80	103.63	<.001
Slow at 63-70% (n=7)	7, 48	62.34	<.001*
Fast at 83-87% (n=10)	7, 72	90.005	<.001
Slow at 83-87% (n=8)	7, 56	65.235	<.001*

*=Significant Levene's test for equality of error variances

In addition to calculating group mean, SD, and CV for MCV, Cohen's *d* was used to demonstrate the magnitude of practical difference in speed between subject groups for each load condition (see tables 3.8-3.10).

Table 3.8 Mean Concentric Velocity (MCV) - Weak vs Strong

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**	**1RM/BM**
Weak (n=10)	Mean	1.19	1.08	0.94	0.80	0.71	0.60	0.51	0.37	1.56
	SD	0.14	0.12	0.10	0.09	0.12	0.09	0.09	0.10	0.20
	CV	12.07	11.27	10.44	10.69	16.85	15.42	18.25	26.91[a]	12.73
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**	**1RM/BM**
Strong (n=8)	Mean	1.11	0.97	0.89	0.73*	0.60	0.54	0.47	0.32	1.98
	SD	0.15	0.10	0.12	0.09	0.08	0.06	0.05	0.05	0.16
	CV	13.62	10.79	13.13	12.74	14.20	11.75	11.72	16.06[a]	8.20
Cohen's *d*		0.53[x]	0.95[x]	0.38[y]	0.78[x]	1.06[†]	0.71[x]	0.53[x]	0.68[x]	2.35[†]

*=Significant (*p< 0.05*) difference in mean MCV compared to previous intensity from Bonferroni post-hoc analysis. [a]= Significant (*p< 0.05*) Leven's test of equality of error variances. [†]=Large, [x]=Moderate, [y]=Small Effect Size, Rhea (2004).

Table 3.9 MCV through all loads: Slower vs. Faster group differentiated by MCV at 63-70% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**	**1RM/BM**
Slower Group (n=11)	Mean	1.12	0.99*	0.88	0.71*	0.60	0.52	0.46	0.31*	1.84
	SD	0.15	0.11	0.10	0.06	0.10	0.05	0.06	0.06	0.15
	CV	13.08	10.77	11.28	8.26	16.00	10.44	13.13	20.71	8.19
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**	**1RM/BM**
Faster Group (n=7)	Mean	1.21	1.10	0.98	0.86	0.76	0.66	0.54	0.40	1.59
	SD	0.14	0.13	0.09	0.06	0.07	0.04	0.09	0.09	0.39
	CV	11.70	11.75	9.39	6.71	9.38	6.22	16.01	22.16	24.60
Cohen's *d*		0.66[x]	0.91[x]	1.03[†]	2.51[†]	1.91[†]	2.84[†]	1.03[†]	1.11[†]	0.85[x]

*=Significant (*p< 0.05*) difference in mean MCV compared to previous intensity from Bonferroni post-hoc analysis. [†]=Large, [x]=Moderate, [y]=Small Effect Size, Rhea (2004).

Table 3.10 MCV through all loads: Slower vs. Faster group as differentiated at 83-87% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**	**1RM/BM**
Slower (n=10)	Mean	1.12	1.00*	0.88	0.71*	0.59	0.51	0.46	0.31*	1.83
	SD	0.15	0.11	0.10	0.06	0.10	0.05	0.06	0.06	0.15
	CV	13.80	11.07	11.59	8.54	16.84	9.39	13.82	20.78	8.36
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**	**1RM/BM**
Faster (n=8)	Mean	1.21	1.08	0.96	0.83	0.74	0.65	0.53	0.40	1.63
	SD	0.13	0.13	0.10	0.08	0.08	0.04	0.08	0.08	0.39
	CV	11.11	12.42	10.57	9.82	10.68	6.35	16.09	20.64	23.57
Cohen's *d*		0.62^{x}	0.65^{x}	0.71^{x}	$1.67^{\dagger}$	$1.66^{\dagger}$	$3.11^{\dagger}$	0.87^{x}	$1.24^{\dagger}$	0.66^{x}

*=Significant ($p < 0.05$) difference in mean MCV compared to previous intensity from Bonferroni post-hoc analysis.
†=Large, ^{x}=Moderate, ^{y}=Small Effect Size, Rhea (2004).

DISCUSSION

In this study, there was the attempt to organize participants based on measures that would differentiate them in a practical manner with regard to the strength and conditioning setting while also demonstrating performance differences based on underlying strength characteristics. The choice to organize and compare participant groups based on relative strength was done primarily in an attempt to identify higher levels of both strength and squat performance.

Effect size calculations between subject groups revealed practical differences at all loads, which every difference being of at least a moderate effect except one (weak vs. strong at 50-57%1RM). The subject groups comparisons based on MCV at 63-70% and 83-87% had greater incidence of large practical effects than did group comparison by relative strength, with subjects grouped by their MCV at 63-70% having the most. Siegel et al. (2002) suggested that the 50-70% 1RM range was optimal for power output in the squat. It is possible that dividing participants at this range more clearly differentiated them based on their power. However, this would seem to contradict the idea put forward by Schmidtbleicher (1992) that strength is the overall most important factor in power production since the faster group was weaker than the slower.

While MCV for all participant groups displayed a downward linear pattern as was expected from previous examples in the literature (Banyard, Nosaka, & Haff, 2017; González-Badillo & Sánchez-Medina, 2010; Jidovtseff, Harris, Crielaard, & Cronin, 2011; Picerno et al., 2016; Sánchez-Medina, Pallarés, Pérez, Morán-Navarro, & González-Badillo, 2017), there were several unexpected outcomes to the testing. Contrary to what was hypothesized, weaker participants tended to perform at higher velocities across all loading conditions. Sorted by relative strength alone (Weak vs. Strong participant groups), the stronger group performed their squats at a slower MCV at all loading conditions. Similarly, when the participants were regrouped based on their MCVs at 63-70% and 83-87% 1RM, the faster group in each case was weaker in terms of mean relative strength. The author hypothesizes that absolute load lifted could account for this difference between subject groups. Logically, the mechanical disadvantage experienced in the "sticking region" of the back squat, which occurs generally in the early part of the concentric phase and is marked by a decrease in velocity (McLaughlin et al., 1977; van den Tillar et al., 2014; Kompf & Arandjelovic, 2017), would be more extreme while squatting 200 kg than with 100kg regardless of strength level.

The above findings contradict those of Sanchez-Medina et al. (2017), who demonstrated similar mean velocity values at given percentages of 1RM across groups with different relative strength levels as measured by a linear position transducer. However, their results do indicate a possibility for the influence of absolute load, as their strongest group performed slower in certain ranges, though the difference was not statistically significant. Furthermore, their strong group was notably weaker than the one in this study, with a mean 1RM and relative strength ratio of 126.4±22.9kg and 1.68±0.16, respectively.

The results of this study were partially consistent with data shown by Zourdos et al. (2016), in which stronger, more experienced lifters were shown to display significantly lower velocities at 90% and 100%1RM. The groups of that study were primarily organized by training age, but it is possible that overall strength may have been a factor in the velocity differences.

Prior training history is likely to have influenced the outcomes of this study. Specificity of training plays a large role in movement velocity (Zatsiorsky, 1995; Verkhoshansky & Siff, 2009). All participants were active in weight training, but several were training specifically for the sport of weightlifting, which emphasizes high-velocity movement. This specific training history may have influenced participant groupings and results.

A threat to internal validity in this study was the method of 1RM testing based on participants' estimation. Though all participants were very familiar with the back squat and had been involved in a training program for a minimum of six months prior to testing, the process of attempting to capture data at set percentage intervals of 1RM may have produced some error. Both slow participant groups also showed significance for Levene's test in their one-way ANOVAs, which was most likely due to the greater variance shown in their higher percentage 1RM trials. An inaccurate low estimate of 1RM would potentially result in participants making substantial load increases after they attained their estimate. It is possible that they could not have made the larger increase needed, but could have completed a repetition at a slightly lighter weight. If this is the case, then their %1RM velocities could be biased toward higher percentages and thus influence data analysis and group differentiation, as well as account for some variance present in the data. The significance of Levene's test in the case of the 100%1RM trial for groups based on relative strength may illustrate this. In future research on this topic, it would be advantageous to test participants multiple times in a similar manner to this study in order to secure more usable data for analysis and ascertain a more accurate 1RM over multiple trials.

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CHAPTER 4

THE RELATIONSHIPS BETWEEN THE VELOCITIES OF THE ECCENTRIC AND CONCENTRIC PHASES OF THE BACK SQUAT

ABSTRACT

by

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The velocity associated with different phases of the back squat may interact to influence the successful completion of a repetition. This association may be further influenced by an individual's level of strength, or their ability to move a relative load (%1RM/body mass) with greater ease. PURPOSE: To examine the relationships between phase velocity characteristics in the back squat and the influence of relative strength on them. METHODS: Healthy male participants (N=18) experienced in the back squat performed repetitions at regular relative intensity (%1RM) intervals of their estimated one-repetition maximum (1RM). Participants were then grouped according to relative strength (1RM/body mass), as well as mean concentric velocity (MCV) at commonly prescribed levels of relative intensity (63-70%1RM, 83-87%1RM). The association of peak and mean concentric and eccentric back squat velocity was examined across the relative loading spectrum through correlation using Pearson's *r.* RESULTS: When considered as a single group, the participants' squats showed at least a moderate ($r = 0.3$) positive level of association between all velocity categories. In general, the associations of the velocity measures for all subjects and group comparisons became weaker as the load increased. DISCUSSION: The relationship between squat phase velocities can be influenced by multiple factors. These include, but are not limited to, base strength level, individual technique differences, and prior training history. Additional factors such as the "sticking region," absolute load, and the stretch-shortening cycle may also influence these relationships. Further investigation is needed in order to uncover the nature of these specific influences on the relationship between squat phase velocities.

Keywords: Back Squat, Load-Velocity Relationships, Strength, Eccentric Velocity

INTRODUCTION

The squatting movement is viewed as a fundamental movement skill. Proficiency in it is greatly beneficial to children and adolescents in order to master optimal movement strategies during growth and development (Kushner et al., 2015; Lubans et al., 2010). The back squat, named for the position of the barbell relative to the body, is a foundational movement in strength and conditioning for sport performance. Mastery of the lift is extremely important, and has been recommended both as a prerequisite to heavy resistance training as well as a movement screening assessment (Myer et al., 2014; Myer et al., 2011).

The use of the back squat is widespread throughout the sporting world and rehabilitation settings as a means to enhance lower body strength (Comfort et al., 2018; Ecamilla, 2001; Ebben & Blackard, 2001). It has even been proposed as a standard assessment of performance-limiting factors. Strength in the back squat has been correlated with performance in many sporting tasks, especially those requiring high power outputs such as jumping and sprinting (Comfort, McMahon, & Suchomel, 2018; Suchomel, Nimphius & Stone, 2016; Chelly et al., 2009; Wisloff et al., 2004).

Power may be the most important factor in athletics, as the athlete who accomplishes the given work quicker is most likely to win (Stone, Stone & Sands, 2007). Velocity is of particular interest because of its relation to the basic power equation (Power = force x velocity). As it is expressed here, power is the product of external force and the velocity of an object in the direction the force is exerted.

In recent years, velocity-based training (VBT) has arisen as a method of exercise intensity prescription (Gonzalez-Badillo & Sanchez-Medina, 2010; Jovanovic & Flanagan, 2014; Mann, Ivey, & Sayers, 2015). VBT has been put forward as a way to autoregulate training intensity to compensate for outside stressors, as well as a means to enhance specificity of training (Mann, Ivey, & Sayers, 2015). The variable most typically monitored in VBT is mean concentric velocity (MCV).

Though MCV is important, eccentric velocity and force production is often overlooked. The inability to generate high eccentric forces could not only compromise the concentric movement phase, but also illustrate a lessened ability to negotiate eccentric forces on the field of play (Stone, Stone & Sands, 2007). Recently, considerable interest has been paid to the interaction between eccentric and concentric phases of resistance exercise, particularly with an altered eccentric phase either through duration or overload (Munger et al., 2017; Wagle et al., 2018, 2017; Wagle et al., 2018). In these studies; however, the emphasis has largely been on the effect of the eccentric portion of the lift on the completion of the concentric, not the relationship of the two across different loading parameters. The purpose of this study was to examine the relationships between peak and mean eccentric and concentric velocities throughout a range of loads in the back squat between participants of different strength levels and velocities at certain relative loads.

METHODS

Participants

Eighteen male (N=18) students experienced in resistance training were recruited for this study. In order to meet the inclusion criteria for the study, all participants had to be at least 18 years of age, free of musculoskeletal injury, participating in weight training for at six months, and familiar with the back squat exercise.

Participants reported to the lab where they first read and signed a written informed consent document approved by the East Tennessee State University Institutional Review Board. After reviewing and signing the informed consent document, the participants were asked to complete a pre-participation survey in order to ensure that they met the inclusion criteria for the study. Following the survey, the participant's height and weight were taken and they were asked to give an estimate of their back squat 1RM.

Table 4.1 Participant Data (N=18)

	Age (yrs)	Training Age (yrs)	Height (cm)	Body Mass (kg)	1RM/BM	1RM (kg)
Mean	26.11	7.10	176.46	90.97	1.74	159.50
SD	5.76	6.41	6.41	9.75	0.29	36.17

Procedures

Upon completion of the pre-participation screening, the participants entered the lab to begin testing procedures (see table 4.2).

Table 4.2 Testing Procedures

General Warm-up:	
25 Jumping Jacks	
10 Bodyweight Squats	
Dynamic Stretching	
Back Squat Testing	
%Estimated 1RM	Repetitions
20%	2
30%	2
40%	2
50%	2
60%	2
70%	2
75%	1
80%	1
85%	1
90%	1
95%	1
100%	1

Means were calculated for all variables at relative loads involving two repetitions. Participants were instructed to complete the repetitions explosively, in order to ensure better accuracy in the load-velocity relationships.

If the participants' 1RM estimations were low, they were asked to continue moving up in weight at 5% increments of their estimated 1RM (105%, 110%, etc.) until they were judged to have reached their maximum weight or failed an attempt. Failure was defined as the participant not reaching a depth at which their thighs were parallel to the floor, or the inability to complete the concentric portion of the repetition. The participants' heaviest completed repetition was counted at their 1RM (100%) and relative percentages for all other loads lifted were recalculated based on this. From this recalculation, the repetitions were organized into groups representing similar percentage ranges of 1RM.

Once the data was collected, participant groups were differentiated in three ways: 1. Relative strength (1RM/body mass) (weak n=10, strong n=8), 2. MCV at a moderate load (slow m=11, fast n=7), and 3. MCV at a heavy load (slow n=10, fast n=8) (see tables 4.3, 4.4, & 4.5). Group composition was determined by dividing participants at the 50th percentile for the above-mentioned variables. For the moderate and heavy load used to reorganize participant groups, the ranges of 63-70%1RM and 83-87%1RM were chosen, respectively. These ranges represent commonly prescribed loads by strength and conditioning professionals.

Table 4.3 Participant Group Data - Weak vs. Strong

			Weak (n=10)			
	Age (yrs)	Training Age (yrs)	Height (cm)	Body Mass (kg)	1RM (kg)	1RM/BM
Mean	26.10	6.20	175.56	89.67	139.50	1.55
SD	5.57	6.35	6.69	10.20	27.24	0.21
CV	21.33	102.45	3.81	11.38	19.52	13.34
			Strong (n=8)			
	Age (yrs)	Training Age (yrs)	Height (cm)	Body Mass (kg)	1RM (kg)	1RM/BM
Mean	26.13	8.22	177.59	92.59	184.50	1.98
SD	6.38	6.73	6.30	9.58	30.62	0.16
CV	24.42	81.90	3.55	10.35	16.59	8.20

Table 4.4 Participant Group Data - Differentiated by MCV at 63-70% 1RM

Slower Group (n=11)							
	Load at 63-70% (kg)	Age (yrs)	Training Age (yrs)	Height (cm)	1RM (kg)	Body Mass (kg)	1RM/BM
Mean	112.36	26.00	7.70	176.26	168.36	91.52	1.84
SD	12.40	6.23	6.67	6.47	21.71	8.79	0.15
CV	11.04	23.96	86.59	3.67	12.89	9.61	8.19
Faster Group (n=7)							
	Load at 63-70% (kg)	Age (yrs)	Training Age (yrs)	Height (cm)	1RM (kg)	Body Mass (kg)	1RM/BM
Mean	98.86	26.29	6.14	176.77	145.57	90.10	1.59
SD	29.86	5.41	6.36	6.81	50.50	11.80	0.39
CV	30.21	20.57	103.57	3.85	34.69	13.09	24.60

Table 4.5 Participant Group Data - Differentiated by MCV at 83-87% 1RM

Slower Group (n=10)							
	Load at 83-87% (kg)	Age (yrs)	Training Age (yrs)	Height (cm)	1RM	Body Mass (kg)	1RM/BM
Mean	141.00	26.10	7.98	176.21	165.90	90.84	1.83
SD	17.44	6.56	6.97	6.82	21.20	8.96	0.15
CV	12.37	25.12	87.38	3.87	12.78	9.87	8.36
Faster Group (n=8)							
	Load at 83-87% (kg)	Age (yrs)	Training Age (yrs)	Height (cm)	1RM	Body Mass (kg)	1RM/BM
Mean	128.38	26.13	6.00	176.78	151.50	91.13	1.63
SD	41.42	5.03	5.90	6.30	49.67	11.30	0.39
CV	32.27	19.24	98.40	3.57	32.79	12.40	23.57

Instrumentation

A combination scale and stadiometer was used to measure the participants' height and weight. Back squat 3D motion analysis was captured using four Vicon T010 cameras (Vicon Motion Systems Ltd.; Oxford, UK) and Vicon Nexus 1.8.5 software (see Figure 4.1). Velocity analyses determined mean and peak concentric and eccentric (MCV, PCV, MEV, PEV) values. Data were transported into R custom coding statistical analysis software. (version 3.5.2; The R Foundation) to calculate the above dependent variables.

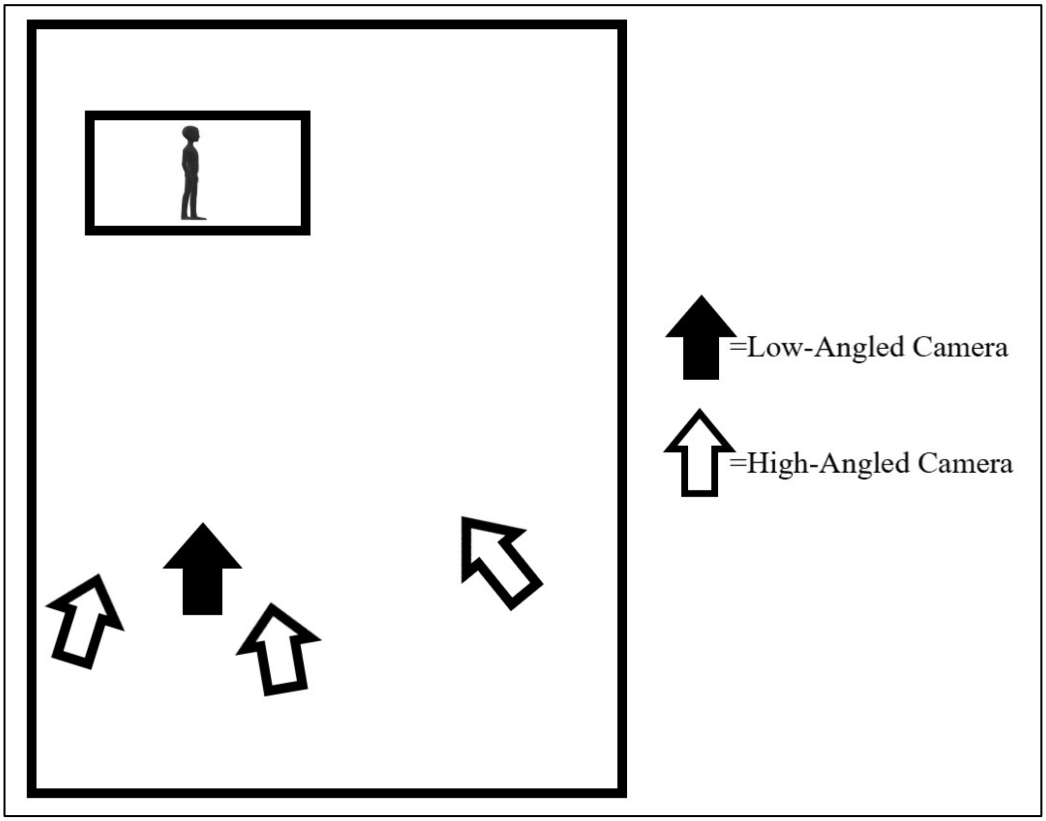

Figure 4.1 4-camera VICON data collect diagram

Statistical Analyses

Means, standard deviations (SD) and coefficients of variation (CV) for all participants (N=18) were determined for MEV, PEV, MCV, and PCV at all relative load conditions. This process was then completed for the previously mentioned participant groupings based on relative strength, MCV at 63-70% 1RM, and MCV at 83-87% 1RM. The association of MEV, PEV, MCV, and PCV during the back squat was across the relative loading spectrum was determined using Pearson's *r.* Correlation magnitude was judged with thresholds of 0.1, 0.3, 0.5, 0.7, and 0.9 for small, moderate, large, very large, and extremely large, respectively (Hopkins et al., 2009).

RESULTS

Group Velocity Characteristics

All participants (N=18) and all participant group mean values for MEV, PEV, MCV, and PCV are displayed in Appendix A.

Squat Phase Velocity Correlations

All correlation tables are contained in Appendix B. Back squat velocity measures for all subjects (Table 4.6) were at least moderately correlated ($r > 0.3$, $p < 0.05$) for all variables at every loading condition.

Table 4.6 Squat Phase Velocity Correlation Data for All Subjects (N=18)

	MEV				*PEV*		
	PEV	*MCV*	*PCV*		*MEV*	*MCV*	*PCV*
20-29%	0.95^{z}	0.73^{y}	0.71^{y}	20-29%	0.95^{z}	0.67^{x}	0.65^{x}
36-45%	0.93^{z}	0.83^{y}	0.72^{y}	36-45%	0.93^{z}	0.77^{y}	0.69^{x}
50-57%	0.93^{z}	0.73^{y}	0.47^{b}	50-57%	0.93^{z}	0.70^{y}	0.50^{x}
63-70%	0.92^{z}	0.74^{y}	0.52^{x}	63-70%	0.92^{z}	0.66^{x}	0.52^{x}
75-79%	0.90^{z}	0.81^{y}	0.49^{b}	75-79%	0.90^{z}	0.70^{y}	0.45^{b}
83-87%	0.84^{y}	0.78^{y}	0.45^{b}	83-87%	0.84^{y}	0.59^{x}	0.50^{x}
89-95%	0.86^{y}	0.76^{y}	0.54^{x}	89-95%	0.86^{y}	0.64^{x}	0.49^{b}
100%	0.85^{y}	0.59^{x}	0.58^{x}	100%	0.85^{y}	0.39^{b}	0.49^{b}
	MCV				*PCV*		
	MEV	*PEV*	*PCV*		*MEV*	*PEV*	*MCV*
20-29%	0.73^{y}	0.67^{x}	0.96^{z}	20-29%	0.71^{y}	0.65^{x}	0.96^{z}
36-45%	0.83^{y}	0.77^{y}	0.87^{y}	36-45%	0.72^{y}	0.69^{x}	0.87^{y}
50-57%	0.73^{y}	0.70^{y}	0.80^{y}	50-57%	0.47^{b}	0.50^{x}	0.80^{y}
63-70%	0.74^{y}	0.66^{x}	0.60^{x}	63-70%	0.52^{x}	0.52^{x}	0.60^{x}
75-79%	0.81^{y}	0.70^{y}	0.71^{y}	75-79%	0.49^{b}	0.45^{b}	0.71^{y}
83-87%	0.78^{y}	0.59^{x}	0.41^{b}	83-87%	0.45^{b}	0.50^{x}	0.41^{b}
89-95%	0.76^{y}	0.64^{x}	0.66^{x}	89-95%	0.54^{x}	0.49^{b}	0.66^{x}
100%	0.59^{x}	0.39^{b}	0.52^{x}	100%	0.58^{x}	0.49^{b}	0.52^{x}

^{a}=small effect size, ^{b}=moderate effect size, ^{x}=large effect size, ^{y}=very large effect size, ^{z}=extremely large effect size (Hopkins et al., 2009)

Tables 4.7-4.9 below reveal the changing relationships between MCV, MEV, and PEV through all loading conditions for the participant group comparisons.

Table 4.7 Squat MCV Correlation Data - Weak vs. Strong

	Weak (n=10)		**Strong (n=8)**	
	MEV:MCV	*PEV:MCV*	*MEV:MCV*	*PEV:MCV*
20-29%	0.68^{x}	0.57^{x}	0.73^{y}	0.71^{y}
36-45%	0.82^{y}	0.66^{x}	0.71^{y}	0.82^{y}
50-57%	0.94^{z}	0.76^{y}	0.56^{x}	0.69^{x}
63-70%	0.72^{y}	0.50^{x}	0.59^{x}	0.63^{x}
75-79%	0.87^{y}	0.70^{y}	0.31^{b}	0.31^{b}
83-87%	0.84^{y}	0.66^{x}	0.48^{b}	0.11^{a}
89-95%	0.89^{y}	0.67^{x}	0.31^{b}	0.42^{b}
100%	0.53^{x}	0.30^{b}	0.47^{b}	0.19^{a}

^{a}=small effect size, ^{b}=moderate effect size, ^{x}=large effect size, ^{y}=very large effect size, ^{z}=extremely large effect size, $p < 0.05$ (Hopkins et al., 2009)

Table 4.8 Squat MCV Correlation Data - Slower vs. Faster at 63-70%1RM

	Slower (n=11)		**Faster (n=7)**	
	MEV:MCV	*PEV:MCV*	*MEV:MCV*	*PEV:MCV*
20-29%	0.85[y]	0.79[y]	0.49[b]	0.38[b]
36-45%	0.85[y]	0.89[y]	0.78[y]	0.55[x]
50-57%	0.81[y]	0.88[y]	0.32[b]	-0.03
63-70%	0.73[y]	0.68[x]	0.31[b]	-0.02
75-79%	0.79[y]	0.77[y]	0.73[y]	0.39[b]
83-87%	0.66[x]	0.35[b]	0.49[b]	0.01
89-95%	0.85[y]	0.83[y]	0.61[x]	0.25[a]
100%	0.37[b]	0.11[a]	0.45[b]	0.12[a]

[a]=small effect size, [b]=moderate effect size, [x]=large effect size, [y]=very large effect size, [z]=extremely large effect size, $p < 0.05$ (Hopkins et al., 2009)

Table 4.9 Squat MCV Correlation Data - Slower vs. Faster at 83-87%1RM

	Slower (n=10)		**Faster (n=8)**	
	MEV:MCV	*PEV:MCV*	*MEV:MCV*	*PEV:MCV*
20-29%	0.86[y]	0.80[y]	0.51[x]	0.41[b]
36-45%	0.84[y]	0.90[z]	0.81[y]	0.61[x]
50-57%	0.81[y]	0.87[y]	0.52[x]	0.31[b]
63-70%	0.72[y]	0.67[x]	0.61[x]	0.46[b]
75-79%	0.80[y]	0.80[y]	0.75[y]	0.53[x]
83-87%	0.72[y]	0.49[b]	0.57[x]	0.21[a]
89-95%	0.85[y]	0.84[y]	0.64[x]	0.36[b]
100%	0.28[a]	0.09	0.45[b]	0.13[a]

[a]=small effect size, [b]=moderate effect size, [x]=large effect size, [y]=very large effect size, [z]=extremely large effect size, $p < 0.05$ (Hopkins et al., 2009)

DISCUSSION

Eccentric phase velocities in the squat and their relationship to the concentric are of interest due to the possible influence they impart on the success of a repetition. Eccentric velocity leading into the concentric may enhance concentric force outputs by means of the stretch-shortening cycle. The mechanism responsible for the augmented force production in the concentric phase is unknown, but may include the reutilization of stored elastic energy or the generation of a greater pre-force at the initiation of the concentric phase (Stone, Stone, & Sands, 2007; Finni, Ikegewa, & Komi, 2001). This action can sometimes be observed in weightlifters as they bounce out of the bottom of the clean in order to aid in their recovery phase of the lift, which is a concentric front squat.

Results for the relationships between MCV, MEV, and PEV were examined in detail, as MCV was considered a more complete measure of total squat performance. PCV occurred in the same portion of the movement for all participants, close to when they were in a fully upright standing position. This position was similar to those noted to be optimal for the generation of maximal concentric force in the quadriceps (Schimdt, 1973), and to the position of the "second pull" in weightlifting movements (Enoka, 1979).

Examining the correlation data for the back squat reveals some interesting points, particularly between participant groups. When considered as a single group, the participants' squats showed at least a moderate ($r = 0.3$) positive level of association between all velocity categories. In general, the associations became weaker as the load increased. Much of this is likely due to the participants' strategies of controlling the eccentric portion of the lift. For example, the relationship between MEV and MCV was very large ($r > 0.7$, $p < 0.05$) for all loading conditions except for 100% 1RM, where it decreased to large ($r = 0.59$, $p < 0.05$).

Strong versus weak group comparisons revealed noticeable differences in the relationships between velocity measures. The similar phenomenon of the associations between velocity measures decreasing in magnitude as the load increased took place, but this was expressed differently between groups. At 83-87% 1RM and 89-95%1RM levels, there are at least two degrees difference in the magnitude of association between MEV, PEV, and MCV. It seems likely, based on the relationships shown, that weaker participants were able to maintain similar velocities throughout their squats, while stronger participants' velocities differed by phase.

This difference in the groups may be due to the increased presence of the "sticking region" during the concentric phase. This region is present during the early portion of the concentric phase and is marked by a decrease in velocity (McLaughlin et al., 1977; van den Tillar et al., 2014; Kompf & Arandjelovic, 2017). The difference being more pronounced starting at the 83-87% range corresponds with the Newton et al. (1997) findings relating to the bench press, in which the sticking region was not observable below 85% 1RM. In addition, the moderate negative correlation between MCV and PVC for the strong group at 100% 1RM (see Appendix B) suggests that they were likely to have struggled through a very slow velocity sticking region.

Correlational data for groups as they were differentiated by their MCV at 63-70% and 83-87% 1RM reveal similar patterns in the relationships of the variables to one another. As stated above, the associations are smaller between each variable as the load increases. The notable difference between the two, as well as to the weak and strong group comparison, is the relationship of PEV to MCV for the fast group at 63-70% 1RM group. Again, this is most likely due to individual strategies for controlling the load which were employed in the eccentric phase, as there is a high level of variance for the group in mean PEV across the loads.

Prior training history is likely to have influenced the outcomes of this study. Specificity of training plays a large role in movement velocity (Zatsiorsky, 1995; Verkhoshansky & Siff, 2009). All participants were active in weight training, but several were training specifically for the sport of weightlifting, which emphasizes high-velocity movement. This specific training history may have influenced participant groupings and results. In addition, participants may have developed individual preferences for managing the eccentric phase which may have further complicated results.

A threat to internal validity in this study was the method of 1RM testing based on participants' estimation. Though all participants were very familiar with the back squat and had been involved in a training program for a minimum of six months prior to testing, the process of attempting to capture data at set percentage intervals of 1RM may have produced some error. An inaccurate low estimate of 1RM would potentially result in participants making substantial load increases after they attained their estimate. It is possible that they could not have made the larger increase needed, but could have completed a repetition at a slightly lighter weight. If this is the case, then their %1RM velocities could be biased toward higher percentages and thus influence data analysis and group differentiation, as well as account for some variance present in the data. In future research on this topic, it would be advantageous to test participants multiple times in a similar manner to this study in order to secure more usable data for analysis and ascertain a more accurate 1RM over multiple trials. To the author's knowledge, there are no studies investigating the variability of phase velocity association in the back squat on the basis of participant strength and velocity characteristics. These relationships warrant further investigation.

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CHAPTER 5

SUMMARY AND FUTURE RESEARCH

The purpose of this dissertation was to investigate the relationship between load and the velocity characteristics of the back squat, and the influence of strength on that relationship. This was undertaken primarily with the strength and conditioning professional in mind, as VBT has grown in popularity and the back squat is a very commonly prescribed exercise. Participants in the study performed repetitions of the back squat at different relative intensities in order to create a load-velocity profile of the exercise which could then be analyzed in different participant groupings.

The load-velocity relationship displayed was linear, with velocity decreasing as the load increased. Practical effects were shown for the level of strength in the back squat in relation to the velocity. Weaker subjects, as a group, tended to move faster at all relative loading conditions. However, there was a large amount of variability for velocity between subjects, indicating individual differences in the ability to express velocity and power across a range of loads. When grouped by their ability to express velocity at often-prescribed relative intensities, subject groups showed large variability in strength level, furthering the idea of individuality of load-velocity profiles, which warrants future investigation through research. The idea of grouping athletes by their velocity characteristics at certain loads could prove useful to strength and conditioning coaches, and the implications of these grouping strategies and their efficacy for training prescription should be investigated further. Further research in this area should also incorporate force platforms in order to obtain a more complete profile of the interplay of force and velocity.

Relationships of velocity characteristics in the squat were at least moderately related when all participants were considered as a single group. Increased loading lead to dissociation of the relationships for all participant groups, which may indicate the influence of individual strategies to control the load eccentrically. When participants were sorted by relative strength, the relationships of mean concentric velocity to eccentric characteristics were markedly different at higher relative intensities. This may have been due to the “sticking region” or individual strategies for controlling the eccentric phase. Future research in the relationship of velocity characteristics in the back squat should involve force platforms in order to monitor the generation of eccentric force in relation to individual strategies of controlling the eccentric phase of the lift. Rates of eccentric force development and how they relate to velocity as well as specific regions of the eccentric phase would be interesting as they relate to individual strategies for control.

Future research in back squat velocity characteristics needs to involve a greater number of subjects of both sexes, as well as a wider range of strength levels of each sex. In addition to the use of force platforms for data collection, researchers should utilize a multi-session data collection process across several days to amass more repetitions within certain ranges of relative intensity without accumulated fatigue. Similar research of this nature should also be conducted with other exercises that are typically prescribed by strength and conditioning coaches such as bench press and deadlift.

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APPENDICES

Appendix A

Participant Group Velocity Comparisons

Table x.x Mean and Peak Velocity (m/s) Measures During Squat Phases – All Participants (N=18)

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Mean Eccentric Velocity	Mean	-0.95	-0.87	-0.84	-0.77	-0.68	-0.62	-0.57	-0.55
	SD	0.23	0.22	0.17	0.17	0.19	0.14	0.15	0.16
Peak Eccentric Velocity	Mean	-1.50	-1.38	-1.31	-1.18	-1.07	-0.95	-0.88	-0.88
	SD	0.36	0.34	0.31	0.26	0.30	0.22	0.21	0.25
Mean Concentric Velocity	Mean	1.16	1.03	0.92	0.77	0.66	0.57	0.49	0.35
	SD	0.15	0.12	0.11	0.09	0.12	0.08	0.08	0.08
Peak Concentric Velocity	Mean	1.88	1.71	1.59	1.44	1.33	1.25	1.22	1.06
	SD	0.27	0.22	0.21	0.19	0.23	0.20	0.26	0.24

Table x.x Mean Eccentric Velocity (MEV) - Weak vs Strong

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Weak (n=10)	Mean	1.01	0.96	0.92	0.85	0.77	0.69	0.64	0.62
	SD	0.21	0.22	0.16	0.15	0.20	0.15	0.16	0.15
	CV	20.66	23.02	17.86	17.43	26.36	21.70	24.49	24.84
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Strong (n=8)	Mean	0.88	0.76	0.73	0.67	0.56	0.54	0.48	0.45
	SD	0.24	0.17	0.13	0.13	0.11	0.10	0.10	0.10
	CV	27.22	22.73	17.81	20.17	18.73	17.58	20.15	21.73

Table x.x MEV - Slower vs. Faster at 63-70% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Slower (n=11)	Mean	0.91	0.82	0.77	0.70	0.60	0.55	0.52	0.48
	SD	0.21	0.17	0.17	0.14	0.15	0.09	0.10	0.09
	CV	23.64	21.07	22.09	20.64	24.67	17.04	20.10	19.65
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Faster (n=7)	Mean	1.02	0.96	0.94	0.89	0.80	0.74	0.65	0.66
	SD	0.24	0.27	0.14	0.14	0.21	0.14	0.19	0.17
	CV	23.84	28.52	14.70	15.96	25.97	18.80	28.73	26.11

Table x.x MEV - Slower vs. Faster at 83-87% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Slower (n=10)	Mean	0.91	0.83	0.78	0.70	0.60	0.55	0.52	0.47
	SD	0.23	0.18	0.18	0.15	0.16	0.10	0.11	0.09
	CV	24.74	21.29	22.93	21.17	26.02	17.95	21.23	19.84
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Faster (n=8)	Mean	1.00	0.93	0.91	0.85	0.77	0.72	0.64	0.65
	SD	0.23	0.27	0.15	0.16	0.20	0.14	0.18	0.16
	CV	23.20	29.14	16.54	18.89	26.21	19.47	27.90	25.01

Table x.x Peak Eccentric Velocity (PEV) - Weak vs Strong

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Weak (n=10)	Mean	1.61	1.53	1.44	1.31	1.23	1.05	0.96	0.98
	SD	0.31	0.35	0.32	0.25	0.30	0.21	0.23	0.26
	CV	19.29	22.60	22.22	19.31	24.19	20.28	23.68	26.19
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Strong (n=8)	Mean	1.36	1.19	1.14	1.02	0.88	0.83	0.78	0.75
	SD	0.39	0.24	0.22	0.19	0.19	0.16	0.17	0.17
	CV	29.10	19.93	19.03	18.14	21.10	18.86	21.11	22.65

Table x.x PEV - Slower vs. Faster at 63-70% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Slower (n=11)	Mean	1.43	1.28	1.20	1.07	0.96	0.85	0.80	0.76
	SD	0.38	0.30	0.32	0.23	0.22	0.16	0.18	0.15
	CV	26.27	23.01	26.92	21.39	23.38	18.47	22.74	20.23
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Faster (n=7)	Mean	1.60	1.52	1.47	1.36	1.25	1.11	1.00	1.06
	SD	0.34	0.38	0.22	0.22	0.34	0.21	0.22	0.27
	CV	21.48	24.86	15.10	16.08	26.95	19.02	21.64	25.18

Table x.x PEV - Slower vs. Faster at 83-87% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Slower (n=10)	Mean	1.44	1.29	1.22	1.08	0.97	0.86	0.81	0.76
	SD	0.40	0.31	0.33	0.23	0.23	0.16	0.19	0.16
	CV	27.47	23.99	27.50	21.67	24.10	19.21	23.23	21.35
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Faster (n=8)	Mean	1.57	1.48	1.42	1.31	1.20	1.07	0.96	1.02
	SD	0.33	0.37	0.26	0.26	0.34	0.23	0.23	0.26
	CV	21.00	24.86	18.36	19.72	28.52	21.00	23.60	25.62

Table x.x Mean Concentric Velocity (MCV) - Weak vs Strong

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Weak (n=10)	Mean	1.19	1.08	0.94	0.80	0.71	0.60	0.51	0.37
	SD	0.14	0.12	0.10	0.09	0.12	0.09	0.09	0.10
	CV	12.07	11.27	10.44	10.69	16.85	15.42	18.25	26.91
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Strong (n=8)	Mean	1.11	0.97	0.89	0.73	0.60	0.54	0.47	0.32
	SD	0.15	0.10	0.12	0.09	0.08	0.06	0.05	0.05
	CV	13.62	10.79	13.13	12.74	14.20	11.75	11.72	16.06

Table x.x MCV: Slower vs. Faster at 63-70% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Slower Group (n=11)	Mean	1.12	0.99	0.88	0.71	0.60	0.52	0.46	0.31
	SD	0.15	0.11	0.10	0.06	0.10	0.05	0.06	0.06
	CV	13.08	10.77	11.28	8.26	16.00	10.44	13.13	20.71
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**1.0000**
Faster Group (n=7)	Mean	1.21	1.10	0.98	0.86	0.76	0.66	0.54	0.40
	SD	0.14	0.13	0.09	0.06	0.07	0.04	0.09	0.09
	CV	11.70	11.75	9.39	6.71	9.38	6.22	16.01	22.16

Table x.x MCV: Slower vs. Faster at 83-87% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Slower (n=10)	Mean	1.12	1.00	0.88	0.71	0.59	0.51	0.46	0.31
	SD	0.15	0.11	0.10	0.06	0.10	0.05	0.06	0.06
	CV	13.80	11.07	11.59	8.54	16.84	9.39	13.82	20.78
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Faster (n=8)	Mean	1.21	1.08	0.96	0.83	0.74	0.65	0.53	0.40
	SD	0.13	0.13	0.10	0.08	0.08	0.04	0.08	0.08
	CV	11.11	12.42	10.57	9.82	10.68	6.35	16.09	20.64

Table x.x Peak Concentric Velocity (PCV) - Weak vs Strong

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Weak (n=10)	Mean	1.91	1.77	1.61	1.48	1.37	1.32	1.30	1.14
	SD	0.27	0.23	0.20	0.17	0.22	0.19	0.27	0.23
	CV	13.92	13.04	12.68	11.57	15.85	14.50	20.87	20.20
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Strong (n=8)	Mean	1.83	1.65	1.57	1.39	1.27	1.17	1.13	0.94
	SD	0.28	0.21	0.23	0.22	0.25	0.20	0.23	0.21
	CV	15.32	12.80	14.38	15.77	19.95	17.38	20.48	21.77

Table x.x PCV - Slower vs. Faster at 63-70% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Slower (n=11)	Mean	1.82	1.66	1.55	1.38	1.27	1.18	1.13	1.01
	SD	0.27	0.19	0.20	0.19	0.26	0.18	0.25	0.19
	CV	14.96	11.52	13.16	13.91	20.17	15.62	22.22	19.02
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Faster (n=7)	Mean	1.96	1.79	1.66	1.54	1.42	1.37	1.37	1.13
	SD	0.26	0.26	0.21	0.16	0.17	0.19	0.22	0.29
	CV	13.18	14.69	12.81	10.63	11.88	14.03	16.37	25.98

Table x.x PCV - Slower vs. Faster at 83-87% 1RM

	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Slower (n=10)	MEAN	1.81	1.68	1.56	1.40	1.28	1.18	1.15	1.01
	SD	0.28	0.20	0.21	0.19	0.27	0.19	0.26	0.20
	CV	15.70	11.68	13.34	13.40	20.92	16.43	22.77	19.87
	%1RM	**20-29%**	**36-45%**	**50-57%**	**63-70%**	**75-79%**	**83-87%**	**89-95%**	**100%**
Faster (n=8)	MEAN	1.96	1.76	1.62	1.49	1.39	1.34	1.32	1.11
	SD	0.24	0.26	0.22	0.20	0.18	0.19	0.25	0.28
	CV	12.22	14.89	13.31	13.46	12.98	14.34	18.58	25.19

Appendix B

Squat Phase Velocity Correlation Tables

All Participants (N=18) velocity correlations at 20-29% 1RM

	MEV	*PEV*	*MCV*	*PCV*
MEV	1.00			
PEV	0.95	1.00		
MCV	0.73	0.67	1.00	
PCV	0.71	0.65	0.96	1.00

All Participants (N=18) velocity correlations at 36-45% 1RM

	MEV	*PEV*	*MCV*	*PCV*
MEV	1.00			
PEV	0.93	1.00		
MCV	0.83	0.77	1.00	
PCV	0.72	0.69	0.87	1.00

All Participants (N=18) velocity correlations at 50-57% 1RM

	MEV	*PEV*	*MCV*	*PCV*
MEV	1.00			
PEV	0.93	1.00		
MCV	0.73	0.70	1.00	
PCV	0.47	0.50	0.80	1.00

All Participants (N=18) velocity correlations at 63-70% 1RM

	MEV	*PEV*	*MCV*	*PCV*
MEV	1.00			
PEV	0.92	1.00		
MCV	0.74	0.66	1.00	
PCV	0.52	0.52	0.60	1.00

All Participants (N=18) velocity correlations at 75-79% 1RM

	MEV	*PEV*	*MCV*	*PCV*
MEV	1.00			
PEV	0.90	1.00		
MCV	0.81	0.70	1.00	
PCV	0.49	0.45	0.71	1.00

All Participants (N=18) velocity correlations at 83-87% 1RM

	MEV	*PEV*	*MCV*	*PCV*
MEV	1.00			
PEV	0.84	1.00		
MCV	0.78	0.59	1.00	
PCV	0.45	0.50	0.41	1.00

All Participants (N=18) velocity correlations at 89-95% 1RM

	MEV	*PEV*	*MCV*	*PCV*
MEV	1.00			
PEV	0.86	1.00		
MCV	0.76	0.64	1.00	
PCV	0.54	0.49	0.66	1.00

All Participants (N=18) velocity correlations at 100% 1RM

	MEV	*PEV*	*MCV*	*PCV*
MEV	1.00			
PEV	0.85	1.00		
MCV	0.59	0.39	1.00	
PCV	0.58	0.49	0.52	1.00

Weak vs. Strong group velocity correlations at 20-29% 1RM

	Weak (n=10)				*Strong (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.93	1.00			0.96	1.00		
MCV	0.68	0.57	1.00		0.73	0.71	1.00	
PCV	0.74	0.63	0.97	1.00	0.67	0.66	0.96	1.00

Weak vs. Strong group velocity correlations at 36-45% 1RM

	Weak (n=10)				*Strong (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.92	1.00			0.89	1.00		
MCV	0.82	0.66	1.00		0.71	0.82	1.00	
PCV	0.75	0.58	0.89	1.00	0.61	0.83	0.84	1.00

Weak vs. Strong group velocity correlations at 50-57% 1RM

	Weak (n=10)				*Strong (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.90	1.00			0.90	1.00		
MCV	0.94	0.76	1.00		0.56	0.69	1.00	
PCV	0.69	0.53	0.77	1.00	0.28	0.59	0.83	1.00

Weak vs. Strong group velocity correlations at 63-70% 1RM

	Weak (n=10)				*Strong (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.88	1.00			0.88	1.00		
MCV	0.72	0.50	1.00		0.59	0.63	1.00	
PCV	0.50	0.24	0.55	1.00	0.34	0.65	0.66	1.00

Weak vs. Strong group velocity correlations at 75-79% 1RM

	Weak (n=10)				*Strong (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.87	1.00			0.87	1.00		
MCV	0.87	0.70	1.00		0.87	0.70	1.00	
PCV	0.54	0.25	0.78	1.00	0.54	0.25	0.78	1.00

Weak vs. Strong group velocity correlations at 83-87% 1RM

	Weak (n=10)				*Strong (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.79	1.00			0.77	1.00		
MCV	0.84	0.66	1.00		0.48	0.11	1.00	
PCV	0.47	0.26	0.51	1.00	0.10	0.63	0.04	1.00

Weak vs. Strong group velocity correlations at 89-95% 1RM

	Weak (n=10)				*Strong (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.84	1.00			0.81	1.00		
MCV	0.89	0.67	1.00		0.31	0.42	1.00	
PCV	0.61	0.40	0.76	1.00	0.07	0.43	0.32	1.00

Weak vs. Strong group velocity correlations at 100% 1RM

	Weak (n=10)				*Strong (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.81	1.00			0.80	1.00		
MCV	0.53	0.30	1.00		0.47	0.19	1.00	
PCV	0.50	0.32	0.74	1.00	0.37	0.44	-0.33	1.00

Slow vs. Fast at 63-70%1RM group velocity correlations at 20-29% 1RM

	Slow (n=11)				*Fast (n=7)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.95	1.00			0.96	1.00		
MCV	0.85	0.79	1.00		0.49	0.38	1.00	
PCV	0.76	0.71	0.96	1.00	0.58	0.48	0.96	1.00

Slow vs. Fast at 63-70%1RM group velocity correlations at 36-45% 1RM

	Slow (n=11)				*Fast (n=7)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.91	1.00			0.94	1.00		
MCV	0.85	0.89	1.00		0.78	0.55	1.00	
PCV	0.62	0.76	0.86	1.00	0.75	0.55	0.88	1.00

Slow vs. Fast at 63-70%1RM group velocity correlations at 50-57% 1RM

	Slow (n=11)				*Fast (n=7)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.94	1.00			0.83	1.00		
MCV	0.81	0.88	1.00		0.32	-0.03	1.00	
PCV	0.45	0.65	0.82	1.00	0.35	0.00	0.75	1.00

Slow vs. Fast at 63-70%1RM group velocity correlations at 63-70% 1RM

	Slow (n=11)				*Fast (n=7)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.91	1.00			0.83	1.00		
MCV	0.73	0.68	1.00		0.31	-0.02	1.00	
PCV	0.34	0.43	0.48	1.00	0.47	0.29	0.54	1.00

Slow vs. Fast at 63-70%1RM group velocity correlations at 75-79% 1RM

	Slow (n=11)				*Fast (n=7)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.90	1.00			0.85	1.00		
MCV	0.79	0.77	1.00		0.73	0.39	1.00	
PCV	0.40	0.56	0.67	1.00	0.45	0.05	0.82	1.00

Slow vs. Fast at 63-70%1RM group velocity correlations at 83-87% 1RM

	Slow (n=11)				Fast (n=7)			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.77	1.00			0.71	1.00		
MCV	0.66	0.35	1.00		0.49	0.01	1.00	
PCV	0.09	0.38	-0.09	1.00	0.37	0.25	0.42	1.00

Slow vs. Fast at 63-70%1RM group velocity correlations at 89-95% 1RM

	Slow (n=11)				Fast (n=7)			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.79	1.00			0.88	1.00		
MCV	0.85	0.83	1.00		0.61	0.25	1.00	
PCV	0.42	0.48	0.57	1.00	0.48	0.17	0.59	1.00

Slow vs. Fast at 63-70%1RM group velocity correlations at 100% 1RM

	Slow (n=11)				Fast (n=7)			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.77	1.00			0.78	1.00		
MCV	0.37	0.11	1.00		0.45	0.12	1.00	
PCV	0.35	0.26	0.31	1.00	0.66	0.53	0.59	1.00

Slow vs. Fast at 83-87%1RM group velocity correlations at 20-29% 1RM

	Slow (n=10)				Fast (n=8)			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.95	1.00			0.97	1.00		
MCV	0.86	0.80	1.00		0.51	0.41	1.00	
PCV	0.78	0.73	0.97	1.00	0.57	0.46	0.94	1.00

Slow vs. Fast at 83-87%1RM group velocity correlations at 36-45% 1RM

	Slow (n=10)				*Fast (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.92	1.00			0.95	1.00		
MCV	0.84	0.90	1.00		0.81	0.61	1.00	
PCV	0.60	0.77	0.86	1.00	0.78	0.60	0.89	1.00

Slow vs. Fast at 83-87%1RM group velocity correlations at 50-57% 1RM

	Slow (n=10)				*Fast (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.94	1.00			0.88	1.00		
MCV	0.81	0.87	1.00		0.52	0.31	1.00	
PCV	0.44	0.64	0.81	1.00	0.49	0.26	0.80	1.00

Slow vs. Fast at 83-87%1RM group velocity correlations at 63-70% 1RM

	Slow (n=10)				*Fast (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.91	1.00			0.89	1.00		
MCV	0.72	0.67	1.00		0.61	0.46	1.00	
PCV	0.30	0.39	0.46	1.00	0.67	0.58	0.76	1.00

Slow vs. Fast at 83-87%1RM group velocity correlations at 75-79% 1RM

	Slow (n=10)				*Fast (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.91	1.00			0.86	1.00		
MCV	0.80	0.80	1.00		0.75	0.53	1.00	
PCV	0.41	0.56	0.70	1.00	0.53	0.24	0.87	1.00

Slow vs. Fast at 83-87%1RM group velocity correlations at 83-87% 1RM

	Slow (n=10)				*Fast (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.79	1.00			0.77	1.00		
MCV	0.72	0.49	1.00		0.57	0.21	1.00	
PCV	0.09	0.38	-0.09	1.00	0.47	0.39	0.51	1.00

Slow vs. Fast at 83-87%1RM group velocity correlations at 89-95% 1RM

	Slow (n=10)				*Fast (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.82	1.00			0.86	1.00		
MCV	0.85	0.84	1.00		0.64	0.36	1.00	
PCV	0.44	0.46	0.57	1.00	0.52	0.38	0.65	1.00

Slow vs. Fast at 83-87%1RM group velocity correlations at 100% 1RM

	Slow (n=10)				*Fast (n=8)*			
	MEV	*PEV*	*MCV*	*PCV*	*MEV*	*PEV*	*MCV*	*PCV*
MEV	1.00				1.00			
PEV	0.80	1.00			0.78	1.00		
MCV	0.28	0.09	1.00		0.45	0.13	1.00	
PCV	0.40	0.27	0.37	1.00	0.68	0.56	0.59	1.00

Appendix C

Participant Screening Survey

Participant Screening Survey

Name_______________________________________-

Date____

Are currently over the age of 18? ____________________

Are you free of musculoskeletal injury? ____________________

Have you participated in physical activity, training, or sports consistently over the last 6 months? If so please circle the best description of your previous activity below.

YES NO

Aerobic/Running/Cycling Strength Training Team Sport Other____________________

How long have you participated in sport? _________________
How long have you participated in strength training? _________________

VITA

THADDEUS JOSEPH LIGHT

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	B.A., History, West Virginia University, Morgantown, WV 2010
	M.S., Kinesiology – Sports Performance, Louisiana Tech University, Ruston, LA 2015
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	Journal Editorial Staff, NSCA Personal Trainer Quarterly and NSCA Coach, National Strength and Conditioning Association, 2018-Present
Publications:	Bernards, J. R, Blaisdell, R. & Light, T. J. (2017). Prescribing an annual plan for the competitive surfing athlete: Optimum methods and barriers to implementation. Strength & Conditioning Journal, 39(6), 26-45. doi: 10.1519/SSC.0000000000000335

Conference Presentations/Posters:

Light, T. J. "Practical Exercise Technique for High School Athletes." Presentation at the ETSU Center of Excellence/Watauga Orthopaedic High School Strength & Conditioning Clinic, Bristol, TN, July 2016

Light, T. J. "The Importance of Strength and Conditioning for the Developing Athlete." Presentation at the Knoxville Orthopaedic Clinic Sports Medicine Day, Knoxville, TN, April 28, 2018.

Light, T. J. "Training the fringes: The role of strength and conditioning as preventative medicine for child and older adult populations." Presentation at the West Virginia School of Osteopathic Medicine, Lewisburg, WV, May 24, 2018.

Szymanski, D. J., Light, T. J., Voss, Z. J., & Greenwood, M. (2015, February). Relationships between vision performance scores and offensive statistics of collegiate baseball hitters. Abstract. Presented at the 2015 South Eastern ACSM Annual Meeting.

Bernards, J.R., Light, T. J., Flynn, A., Keck, S., Powell, L. (2016, December). Simple Reaction Time Characteristics Among Male and Female College Athletes. Poster presented at 10th Annual ETSU Coaches College Conference.

Honors and Awards:

Graduate Research Award, Louisiana Tech University College of Education, Department of Kinesiology, 2015

American Kinesiology Association Master’s Scholar Award, 2015.