2019

Using Maximum Power as a Variable for 1RM Prediction in the Squat and Bench Press

Sean O'Connor
South Dakota State University

USING MAXIMUM POWER AS A VARIABLE FOR 1RM PREDICTION IN THE SQUAT AND BENCH PRESS

BY

SEAN O'CONNOR

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Nutrition and Exercise Science

Specialization in Exercise Science

South Dakota State University

2019

2019

USING MAXIMUM POWER AS A VARIABLE FOR 1RM PREDICTION IN THE SQUAT AND BENCH PRESS

SEAN O'CONNOR

This thesis is approved as a creditable and independent investigation by a candidate for the Master's of Science in Nutrition and Exercise Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Matthew Vukovich, Ph.D. — Date
Thesis advisor

Kendra Kattelmann, Ph. D. — Date
Head, Department of Health and Nutritional Science

Dean, Graduate School — Date

ACKNOWLEDGEMENTS

I would like to acknowledge my thesis advisor Dr. Matthew Vukovich for his tremendous help and guidance put in to this project. I would also like to thank Ross Canales for his help with the initial pilot testing as well as data collection. I'd also like to express a great deal of appreciation to the South Dakota State University student-athletes that volunteered to participate in my study. Finally, I would like to acknowledge my family, friends, and coworkers for their helpful insight and support throughout this process.

CONTENTS

ABBREVIATIONS……………………………………….……………………………v

LIST OF FIGURES………………………………...……………………………vi

LIST OF TABLES…………………………………………...….................….…...vi

ABSTRACT………………………………………………….….................…vii

INTRODUCTION…………………………………………...……………1

REVIEW OF LITERATURE………………………………………………......4

METHODS…………………………………………………………………..6

RESULTS………………………………………………………………………9

DISCUSSION…………………………………………………………....11

LITERATURE CITED…………………………..…………………………………15

FIGURES AND TABLES………………………………………………………….18

ABBREVIATIONS

1LM	one-lift max
1RM	one-rep max
ANOVA	analysis of variance
AP	average power
AV	average velocity
BP	bench press
BW	bodyweight
PP	peak power
PV	peak velocity
r	Pearson correlation coefficient
R^2	coefficient of determination
S	squat
S&C	strength and conditioning
SEE	standard error of estimate

LIST OF FIGURES

Figure 1a. Female power outputs for the bench press and squat exercise (page 18)

Figure 1b. Male power outputs for the bench press and squat exercise (page 19)

LIST OF TABLES

Table 1. Summary of studies (page 4-5)

Table 2. Subject characteristics (page 20)

Table 3. Intensities used to test for squat and bench press exercise for males and females (page 21)

Table 4a. Female squat trial means and standard deviations for average power (AP), average velocity (AV), peak power (PP), and peak velocity (PV) (page 22)

Table 4b. Female bench press trial means and standard deviations for AP, AV, PP, PV (page 23)

Table 4c. Male squat trial means and standard deviations for AP, AV, PP, PV (page 24)

Table 4d. Male bench press trial means and standard deviations for AP, AV, PP, PV (page 25)

Table 5a. Correlations between variables and 1RM for female squat (page 26)

Table 5b. Correlations between variables and 1RM for female bench press (page 27)

Table 5c. Correlations between variables and 1RM for male squat (page 28)

Table 5d. Correlations between variables and 1RM for male bench press (page 29)

ABSTRACT

USING MAXIMUM POWER AS A VARIABLE FOR 1RM PREDICTION IN THE SQUAT AND BENCH PRESS

SEAN O'CONNOR

2019

Many Strength and Conditioning (S&C) coaches utilize a one-rep max (1RM) exercise test to gauge the maximal strength of athletes, and then prescribe resistance training programs based on a relative percentage of 1RM to obtain strength or power adaptations. However, many S&C coaches have raised questions regarding the safety and necessity of a 1RM test. Attempts to mitigate the weaknesses of 1RM testing have led to other methods of testing including repetition max testing (3RM, 5RM, 10RM, etc.) as well as load/velocity profiling. The main purpose of this study is to determine if 1RM can be accurately estimated from maximal power outputs at submaximal loads.

This study consisted of 28 Division I athletes (male=18, female=10). Subjects were tested for 1RM in the squat (S) and bench press (BP) exercises and followed up with maximal power testing at a range of submaximal loads. Power outputs and velocities were measured using a Tendo® Power Analyzer V-316 electronic device.

Significant correlations were found between average power (AP) and 1RM for both males and females in both exercises. Percent 1RM (%1RM) intensities had stronger correlations to actual 1RM (r=0.93, 0.92, 0.91, 0.88) than percent bodyweight (%BW) intensities (r=0.90, 0.87, 0.86, 0.73). However, %BW intensities still possessed adequate correlations to use in the model to predict 1RM with good accuracy.

The results from this study indicate that 1RM's can be accurately predicted from AP measures at submaximal intensities. This method of estimating 1RM may be optimal for athlete safety and most practical for use by S&C coaches.

Chapter 1

Introduction

Currently there are several methods used by Strength and Conditioning (S&C) coaches to measure maximum muscular strength, however there may be more efficient ways of predicting maximum strength that can benefit both the athlete and the S&C coach. Resistance training programs are developed for athletes based on a prescription that relies on relative intensities of a maximal effort. The intensities are based on measuring the maximal force a muscle can generate during a single maximal effort, usually referred to as a one-repetition max (1RM) or one-lift max (1LM). S&C coaches prescribe relative intensities from the 1RM to develop strength or power adaptations. Although performing a 1RM is the most accurate method of measuring strength, it has shortcomings: 1) a 1RM attempt may pose a higher risk of injury and 2) a 1RM attempt requires a significant amount of time for the athletes to prepare for and recover from the attempt [10].

S&C coaches have searched for other options to estimate or predict maximal strength including 3RM, 5RM, 10RM, and load/velocity profiling [3,4,8,11,12,15,17] in order to minimize the shortcomings. However, each of these methods have limitations as well. A repetition max still involves the athlete performing until failure. As the athlete approaches failure, technique begins to break down which may increase their risk of injury. S&C coaches have also criticized this method for having over-estimated 1RM’s. The severe limitation in performing a load/velocity profile is that each individual would require their own linear regression equation which is not practical for S&C coaches in a team setting. This is why we want to study the relationship between power outputs and

1RM. The measurement of power output permits the use of submaximal loading since max power is obtained at lower intensities with minimal repetitions. This is advantageous towards safely and efficiently implementing this testing protocol. The main purpose of this study is to determine if power outputs measured at submaximal intensities in the squat (S) and bench press (BP) exercises can be used to predict 1RM. If completed successfully, this research may result in an effective method for S&C coaches to maintain the accuracy of 1RM predictions while enhancing the feasibility and safety of the strength testing protocol.

Our first specific aim is to determine if predication equations could be developed to calculate 1RM efforts from the measurement of power outputs at submaximal resistances. We hypothesize that average power (AP) will be the variable used in the model to predict 1RM [8,12]. We also hypothesize that the equations will be different for males and females [13,19].

The second aim of the study is to determine the optimal load at which maximum power occurs in the S and BP of collegiate athletes. Based upon previous research [1,2,5,13,18,19], we hypothesize that the optimal load for determining max power in the S will be between 50-65% 1RM or 30-90% bodyweight (BW) and the optimal load for determining maximum power in the BP will be between 40-60% 1RM or 20-60% BW. In order to test this hypothesis, the subjects will be tested for a 1RM in the S and BP. They will follow up with testing for max power outputs at a range of submaximal percentages of 1RM and BW.

Benefits of this study will provide S&C coaches with: 1) a method of testing that may result in reduced injury occurrence, 2) the ability to maintain accurate 1RM's to allow for appropriate future load prescriptions, 3) time efficient implementation, 4) improved athlete recovery from the testing [10], 5) the ability to track and monitor changes in power outputs during a given training cycle. If successful, appropriate next steps will be to utilize this formula to obtain 1RM estimates and to use those estimates when prescribing loading percentages aimed at improving power production.

Chapter 2

Review of Literature

Table 1. Summary of studies.

Study	Subjects, n	Objective	Protocol	Results	Outcomes/Conclusions
Baker et. al. (2010)	31 rugby professional and semi-professional athletes	To determine if any differences occur in power output with various loading intensities of a BP throw exercise	Subjects tested for 1RM on BP. Followed by testing of Pmax on BP Throws at 40, 50, 60, 70, and 80kg absolute loads	Pmax occurred at mean load of 70.1kg representing 54.9% 1RM BP. Pmax output was significantly different from 40, 50, 60, and 80kg loads but not 70kg	Loads close to 55% 1RM in the BP Throw may be optimal when training for maximal power output
Bosquet et. al. (2010)	27 PE students and teachers of varying training histories	Assess validity and accuracy of a commercial linear encoder to estimate BP 1RM from FV relationship	Subjects tested for 1RM BP followed by FV testing beginning at 10kg and ascending 5kg per trial until power measures decreased	Mean 1RM (61.8kg) was highly correlated (r=.93) but largely different from the software estimated mean 1RM (56.4kg)	1RM estimations from FV relationship is useful for tracking training adaptations but not accurate enough to prescribe training intensities
Conceição et. al. (2016)	National/International competitive track & field jumpers and sprinters (n=15)	To investigate the relationship between velocity and load for lower body resistance exercises (full squat, half squat, leg press)	Cross sectional design: 3 sessions, Began exercise testing at low intensities and incrementally added 10% 1RM load for each trial until a 1RM was reached	A strong relationship between Vmax, MPV, and %1RM existed for all 3 exercises	Measuring movement velocity can provide an accurate 1RM estimate
Cormie et. al. (2007)	26 recreationally trained males	Compare power training and strength-power training on the load-power relationship in the jump squat	Power group trained jump squats at optimal power output load. Strength-power group performed jump squats along with 3x3 back squats at 90% 1RM	Power group had significant improvements in PP and JH at BM and lighter loads. Strength-power group had significant improvements in PP and JH across all loads	Mixed strength-power training was as effective as power training at improving max PP and JH, and more effective at producing improvements at higher resistances in the load-power relationship
Cormie et. al. (2007)	12 division I male athletes	To determine which loading intensity maximizes power output in the JS, S, and PC	1RM testing in JS, S, and PC followed by power testing at submaximal loading intervals	JS optimal load: 0% 1RM S optimal load: 56% 1RM PC optimal load: 80% 1RM	The optimal load for max power output occurs at different %'s of 1RM in the JS, S, and PC
Garcia-Ramos et. al. (2017)	30 collegiate men with at least 2 years of resistance training experience	To determine which velocity measurement is the strongest predictor for relative load	A full load-velocity relationship was measured by the subjects performing Bench Press Throws exercise on a Smith Machine	Mean Velocity showed the strongest linearity (r^2=.989 and .993). Followed by MPV (r^2=.983 and .980) then peak velocity (r^2=.974 and .969). Mean velocity also was the most accurate at predicting relative load (SEE=3.8-4.76%1RM)	Mean Velocity could be the optimal variable to monitor relative load in BPT exercise on a Smith Machine
Jidovsteff et. al. (2012)	Meta-analysis (subjects not stated)	To investigate the ability of the load-velocity relationship to predict 1RM in different exercises and with different assessment devices	Data from 4 studies on 5 different strength exercises. Each included 2 sessions (1RM testing and ascending loads velocity testing). Devices used: inertial dynamometer, linear position transducer + accelerometer, myotest accelerometer	Avg Velocity was more effective than peak velocity when estimating 1RM. Prediction ability was greatest for the Bench Press exercise	Prediction ability depends on the complexity of the exercise, characteristics of the machine, and device of measurement. Using the load-velocity relationship can be a relevant method for 1RM prediction when exercise allows accurate velocity measures
Jidovsteff et. al. (2011)	112 recreationally active subjects (90 male, 22 female) from 3 previous studies	To investigate the ability of the load-velocity relationship to predict 1RM in the Bench Press	1RM Bench Press assessment followed by velocity testing at submaximal ascending loads	LD0 corresponded to 116% of 1RM. Average Velocity at 1RM was .23 m/s. Cumulative correlation between 1RM and LD0 for the 3 studies was r=.98	Load-velocity relationship can be used to estimate max strength. Suggests this method is as accurate as reps to failure method.

Kendrick (2008)	67 collegiate athletes	Determine the optimal load to train for power on the plyo-press exercise	Tested for 1RM plyo-press along with power output at different relative loads (%1RM & % body mass). Power output was analyzed using the 3PQ system.	Pmax occurred at 50% BM for females (peak power mean 41.8 watts/kg). Pmax for males occurred at 75% BM for males (peak power mean 39.3 watts/kg). Pmax at 30% 1RM was not significantly different from 75% BM.	Pmax occurs at a different intensity relative to BM for males and females. % BM can potentially be used as an effective substitute for %1RM for Pmax evaluations.
Loturco et. al. (2017)	36 male top level athletes in rugby and combat sports	To determine the force-velocity relationship to predict 1RM in the free weight and Smith machine BP	1RM BP assessment followed by MPV measures for submaximal ascending sets	Predicted 1RM's were not different from actual 1RM's (SM actual=118.1, SM predicted=117.4; FW actual=109.7, FW predicted=108.6).	The linear relationship between MPV and %1RM allow determination of accurate training intensity based on bar velocity
Loturco et. al. (2018)	61 elite athletes with at least 5 years of resistance training experience	To compare associations between 1RM's and Pmax to performance measures	1RM and power outputs were measured for Half-Squat. Power was also measured in Jump-Squat. These values were tested to determine relationship with vertical jumps and sprint times.	Sprint time correlations were stronger for power-related variables (r=-.36 to -.91) versus 1RM values (-.35 to -.69). Only power outputs were significantly related to jump height.	Bar-power outputs were more strongly associated with sprint and jump performance. The bar-power measures may be more effective for athlete testing and monitoring for changes in actual performance.
Ruf et. al. (2018)	11 males with at least 1 year of resistance training experience	To examine the reliability and validity of using submaximal loads' velocities to predict 1RM in the Deadlift	3 different 1RM assessments on 3 different days along with varying submaximal intensities tested for mean velocity on each day	1RM predictions showed high reliability, however predicted 1RM's overestimated actual 1RM's.	1RM predictions based off mean velocity at submaximal loads are highly variable in the deadlift exercise and are not a replacement for actual 1RM measures
Siegel et. al. (2002)	25 college-aged male volunteers with prior resistance training experience	Evaluate the measurement of muscular power during resistance training	Performed BP and S exercises at 30, 40, 50, 60, 70, 80, 90% 1RM. Pmax was measured at each intensity.	No significant relationship between peak power and fiber types. Peak power occurs between 50-70% 1RM for S and 40-60% for BP	The evaluation of muscle power is reliable, but not predictive of fiber type
Stone et. al. (2003)	22 males with variety of resistance training experience	Investigate relationship between 1RM and power output during squat jumps exercise	Subjects divided into strongest and weakest groups based on 1RM Squat. Countermovement and static squat jumps were performed from 10-100% 1RM Squat loads and power measures were recorded.	Strong correlations (r=.77-.94) between 1RM Squat and both countermovement and static squat jump power up to 90% 1RM. Highest power output for both jumps occurred at 10% 1RM. However, for the "strong" group the highest Pmax was at 40% 1RM.	In order to improve jumping power output, improving max strength should be emphasized. Stronger people express Pmax at a higher relative intensity.
Wilson et. al. (1993)	64 subjects with at least 1 year experience resistance training and able to half-squat >Bodyweight	To determine which resistance training method results in greatest enhancement in sports performance.	4 groups underwent a 10week training intervention using: 1) Traditional heavy weight training 2) Plyometric training 3) Explosive weight training at Pmax load 4) Control. Tested at baseline and post for dynamic athletic exercises (sprint, jump)	The explosive weight training group achieved the best overall results in enhancing athletic performance.	Performance gains will be optimized using training loads that maximize power output.

* BP = bench press; 1RM = one repetition maximum; Pmax = maximum power; r = correlation coefficient; PE = physical education; FV = force velocity; Vmax = maximum velocity; MPV = mean propulsive velocity; PP = peak power; JH = jump height; BM = body mass; JS = jump squat; S = squat; PC = power clean; LD0 = load at zero velocity; SM = smith machine; FW = free weight

Chapter 3

Methods

The study consisted of 28 healthy Division I collegiate athletes; 18 males and 10 females. The subjects participated in the following sports: Track and Field (distance runners), Baseball, Wrestling, Swim and Dive, and Golf. All participants had a minimum 15 weeks of experience in a collegiate strength and conditioning program. Subject characteristics are provided in Table 2. Participant consent was obtained in accordance with the policy statements of the Human Subjects Committee at South Dakota State University.

The study consisted of two testing sessions. During the first session, BW was recorded and 1RM was measured. Participants' single maximum lift (1RM) in the S and BP exercises were measured. The 1RM is the greatest weight that can be lifted one time. All S testing required participants to squat to parallel (femur runs parallel to the floor) and keep their feet in contact with the floor at all times (no jumping permitted). All BP testing required participants to lightly touch the bar to the chest while keeping the glutes in contact with the bench. A warm-up for each exercise (S and BP) was performed with a self-selected load that allowed participants to easily complete a minimum of 6-10 repetitions (~50% of their predicted 1RM). A weight was then selected based on previous efforts which allowed subjects to perform 3 repetitions (~80% of their predicted 1RM). Following a 3-minute rest, weight was added to the bar (load increments of 2.5-10kg) and were attempted to lift for one repetition. Heavier subsequent attempts were completed until the subjects could no longer lift the weight unassisted, usually 3-7 trials of increasing weight.

The second testing session was performed sometime between 48 hours and 2 weeks after 1RM testing. The session included testing and recording of power outputs and bar velocities at several submaximal intensities (Table 3) for the S and BP using a Tendo® Power Analyzer V-316 electronic device. This device measures power output by programming the load into the microcomputer and then connecting the wire attachment to the barbell in order to measure barbell velocity during the exercise. The following variables were measured for in this study: Average Power, Peak Power, Average Velocity, and Peak Velocity. Each of these variables were recorded for every repetition of every set for both the S and BP exercises. The participants were instructed to accelerate the bar as fast as possible with each repetition during testing. The S and BP lifts were performed at different resistances based on a percentage of the subjects' bodyweight (BW) and 1RM (Table 3).

All subjects performed an adequate general and specific warm-up to ensure peak performances during testing. Subjects completed 5 minutes of a general warm-up (jumping jacks, bodyweight squats, bodyweight lunges, push-ups) followed by 2-3 sets of a specific warm-up (self-selected loads on the S and BP exercise).

After the warm-up, subjects then performed 3 repetitions of the S and BP exercises at each of the following intensities (Table 3). A minimum of 2 minutes rest was taken in between sets to ensure full recovery. Subjects completed the testing in order from lightest load to heaviest load.

Statistics

A one-way analysis of variance (ANOVA) was used to determine if there were differences between the three repetitions for the performance variables. A one-way ANOVA was also used to determine if measures of power and velocity were different among the resistances. When a significant difference was calculated for the one-way ANOVA's, a Tukey HSD post-hoc test was used to locate significant differences. A simple linear regression was performed to determine if there was a significant relationship between submaximal performance variables and maximal strength measured as a 1RM. A two-tailed t-test was used to determine if the slope was different from zero. Pearson correlation coefficients (r), coefficient of determination (R^2), standard error of estimate (SEE) were calculated to determine the strength of the prediction equation.

Chapter 4

Results

There was no difference among the three trials for all variables measured for both females and males and repetition two was used for all future analyses (Tables 4a, 4b, 4c, 4d).

The measure of AP during the BP at 20% BW and the S exercise at 30% BW was significantly lower than the other resistances for female athletes (Figure 1). The measurement of peak power during the S was significantly lower at 30% and 45% BW compared to the other resistances for female athletes (Figure 1). There were no significant differences among the resistances for both AP and peak power measured during the BP and S exercise for men (Figure 2).

Significant correlations were found between a number of power and velocity measurements and measured 1RM (Tables 5a, 5b, 5c, 5d). The highest correlations were between AP and 1RM for both BP and S in females and males. Within the measurement of AP output, correlations between 1RM and the relative resistance calculated from the 1RM produced the best correlations and lowest SEE.

The resistances associated with a percentage of the individuals' BW were not as strong but did produce some significant relationships (Tables 5a, 5b, 5c, 5d). The highest correlations with the lowest SEE between 1RM and the resistance calculated from BW can be seen highlighted in yellow in (Tables 5a, 5b, 5c, 5d).

The linear regression equations used to predict 1RM were generated from the BW intensities with the highest correlations and lowest standard error as follows:

- Female S @ 60% BW: Estimated 1RM = 16 + .1984819*(AP)
- Female BP @ 40% BW: Estimated 1RM = 5 + 0.187368*(AP)
- Male S @ 110% BW: Estimated 1RM = 62 + 0.1180123*(AP)
- Male BP @ 60% BW: Estimated 1RM = 21 + 0.1697443*(AP)

The linear regression equations used to predict 1RM were generated from the %1RM intensities with the highest correlations and lowest standard error as follows:

- Female S @ 50% 1RM: Estimated 1RM = 16 + 0.1918582*(AP)
- Female BP @ 55% 1RM: Estimated 1RM = 4 + 0.1847638*(AP)
- Male S @ 40% 1RM: Estimated 1RM = 37 + 0.1723215*(AP)
- Male BP @ 45% 1RM: Estimated 1RM = 16 + 0.178556*(AP)

Chapter 5

Discussion

The main purpose of this study was to determine if an individual's maximal strength can be predicted using power output measurements at submaximal intensities. The use of the 1RM test imposes some risk to the athlete and requires time to recover [10], impeding training programs. The ability to utilize a submaximal test to accurately predict a maximal effort would benefit the athlete and the S&C coach.

The results of our study indicate the variable shown to have the strongest correlations (r) to 1RM is AP and not peak power for both the S and BP exercises for both males and females (r=0.93, 0.92, 0.91, 0.90, 0.88, 0.87, 0.86, 0.73). This finding is consistent with the findings from studies investigating the measurement of velocity of bar movement during the S and BP as a predictor for 1RM measurements. In those studies, the average velocity was a more effective measure than peak velocity when estimating 1RM's [8,15].

Intensities tested as %1RM generally had higher correlations than the intensities tested as %BW for both the S and BP exercises for both men and women. This finding can be explained by the calculation of %1RM deriving directly from the 1RM itself resulting in stronger correlations versus calculations derived from BW. Although %1RM intensities had stronger correlations with 1RM (r=0.93, 0.92, 0.91, 0.88), %BW also possessed significant relationships between AP and 1RM (r=0.90, 0.87, 0.86, 0.73) and may subsequently be used as an accurate 1RM predictor [13]. The ability to sustain accuracy utilizing %BW as a loading parameter may be explained by the findings of no statistical differences in AP output across a wide range of loading intensities (35-65% 1RM BP and 40-70% 1RM S). Pending adequate access to Tendo® Power Analyzer V-316 electronic units, using AP at a %BW for 1RM prediction could be a very practical method of obtaining 1RM estimates. This method may be more advantageous than a 1RM test to implement with young or relatively untrained athletes that are new to a strength training program. Utilizing AP at a submaximal percentage of individual body weight would provide S&C coaches a method to acquire baseline measures that may allow improved technique during exercise execution, may reduce both the risk of injury and the time needed to measure. This method would also allow precise future load prescription and provide an easy way to track training adaptations over time.

Another aim of this study was to determine which relative intensities permitted the highest power outputs. While there were no statistical differences between power output among the intensities, training adaptations will be influenced by the intensity of the exercise. Training with intensities at or near the highest power outputs may be superior to improving sprint and jump performance versus traditional strength training intensities ~80-95% 1RM [16,21]. However, traditional strength training may improve athletes' general capacity to produce power at higher intensities [6,19]. It is recommended to utilize both power and strength training intensities to optimize athletic performance. A greater emphasis on one or the other should be based upon the athletes' resistance training experience, current strength levels, and sport requirements [20].

Another finding in this study was that average and peak power outputs were similar between repetitions 1, 2, and 3 during testing. This suggests that for S&C

coaches, power can be trained optimally for the S and BP exercises for at least 3 repetitions per set before there is a decline in muscular power production from fatigue.

The traditional model of testing 1RM only provides a measurement of muscular strength. The method proposed in this study utilizes the measurement of power output. Previous research has indicated that bar power outputs have stronger correlations to sprint and jump performance versus 1RM's [16]. This could indicate that improvements in power production may generate more meaningful changes in athletic performance versus improvements in 1RM. Monitoring changes in power production could be of use to S&C coaches to evaluate the outcomes of their training programs.

Other methods that have attempted to predict 1RM include a repetition max test (10RM, 5RM, 3RM, etc.) as well as load/velocity profiles [3,4,8,11,12,15,17]. A large weakness of the repetition max test is that it still involves the lifter performing to muscular failure. Performing to failure is typically accompanied by a breakdown in technique and a heavy reliance on exercise spotters to help recover the attempt safely. This could potentially present an increased risk of injury. Additionally, this method has also been criticized by S&C coaches for overestimations of the true 1RM. The load/velocity profile method has been shown to estimate individual 1RM with a high degree of precision [4,8,11,12,15] however it is much less practical in a group strength and conditioning setting.

The results from this study indicate that 1RM's can be accurately predicted from AP measures at submaximal intensities of either %1RM or %BW. Utilizing %BW as the loading parameter for this testing method would satisfy the main objective of this study which is to avoid the requirement of 1RM testing in the strength and conditioning program. This method of testing could be a useful way for S&C coaches to gauge the strength of an athlete without subjecting them to the risk of maximal loads. In addition, this method of estimating 1RM may be optimal and most practical for use by S&C coaches because: 1) it would be very time efficient and easy to implement in a group setting, 2) there would be less training stress applied, leading to better recovery for subsequent training sessions [10], 3) they would be able to track and monitor changes in power production. Future recommendations would be to use this method to obtain 1RM estimates, then follow up with periodic testing to maintain up-to-date load prescriptions as well as monitor changes in power production.

Literature Cited

1. Baker et al. The Load That Maximizes the Average Mechanical Power Output During Jump Squats in Power-Trained Athletes. *Journal of Strength and Conditioning Research.* 2001.
2. Baker et al. The Load That Maximizes the Average Mechanical Power Output During Explosive Bench Press Throws in Highly Trained Athletes. *Journal of Strength and Conditioning Research.* 2001.
3. Bosquet et al. Validity of a Commercial Linear Encoder to Estimate Bench Press 1 RM from the ForceVelocity Relationship. *Journal of Sports Science and Medicine* 2010.
4. Conceição et al. Movement velocity as a measure of exercise intensity in three lower limb exercises. *Journal of Sports Sciences*. 2015;34(12):1099-1106
5. Cormie et al. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc.* 2007;39(2):340-349.
6. Cormie et al. Power versus strength-power jump squat training: influence on the load-power relationship. *Med Sci Sports Exerc.* 2007;39(6):996-1003.
7. Cronin et al. Challenges in Understanding the Influence of Maximal Power Training on Improving Athletic Performance. *Sports Med.* 2005.
8. Garcia-Ramos et al. Mean Velocity vs. Mean Propulsive Velocity vs. Peak Velocity: Which Variable Determines Bench Press Relative Load With Higher Reliability?. *Journal of Strength and Conditioning Research*. 2017.
9. Gonzalez-Badillo et al. Movement velocity as a measure of loading intensity in resistance training. *Int J Sports Med.* 2010;31(5):347-352.

10. Howatson et al. The response to, and recovery from maximum strength and power training in elite track and field athletes. *International Journal of Sports Physiology and Performance*. 2016;11(3):356-362.

11. Jidovsteff et al. USING THE LOAD-VELOCITY RELATIONSHIP FOR 1RM PREDICTION. *Journal of Strength & Conditioning Research.* 2011.

12. Jidovsteff et al. 1RM PREDICTION AND LOAD-VELOCITY RELATIONSHIP. 2012.

13. Kendrick. The Load That Will Elicit Maximum Power Output of the Lower Extremities on the PlyoPress 625III using the 3PQ. 2008.

14. Loturco et al. Using Bar Velocity to Predict the Maximum Dynamic Strength in the Half-Squat Exercise. *Int J Sports Physiol Perform.* 2016;11(5):697-700.

15. Loturco et al. Predicting the Maximum Dynamic Strength in Bench Press: The High Precision of the Bar Velocity Approach. *Journal of Strength and Conditioning Research*. 2017;31(4):1127-1131.

16. Loturco et al. 1RM Meaures or Maximum Bar-Power Output: Which is More Related to Sport Performance?. *International Journal of Sports Physiology and Performance*. 2018;1-18.

17. Ruf et al. Validity and Reliability of the Load-Velocity Relationship to Predict the One-Repetition Maximum in Deadlift. *Journal of Strength and Conditioning Research*. 2018;32(3):681-689.

18. Siegel et al. Human Muscle Power Output During Upperand Lower-Body Exercises. *Journal of Strength & Conditioning Research.* 2002.

19. Stone et al. Power and Maximum Strength Relationships During Performance of Dynamic and Static Weighted Jumps. *Journal of Strength & Conditioning Research.* 2003.

20. Suchomel et al. The Importance of Muscular Strength in Athletic Performance. *Sports Medicine*, 2016;46(10):1419–1449.

21. Wilson et al. The optimal training load for the development of dynamic athletic performance. *Official Journal of the American College of Sports Medicine*. 1993;1279-1286.

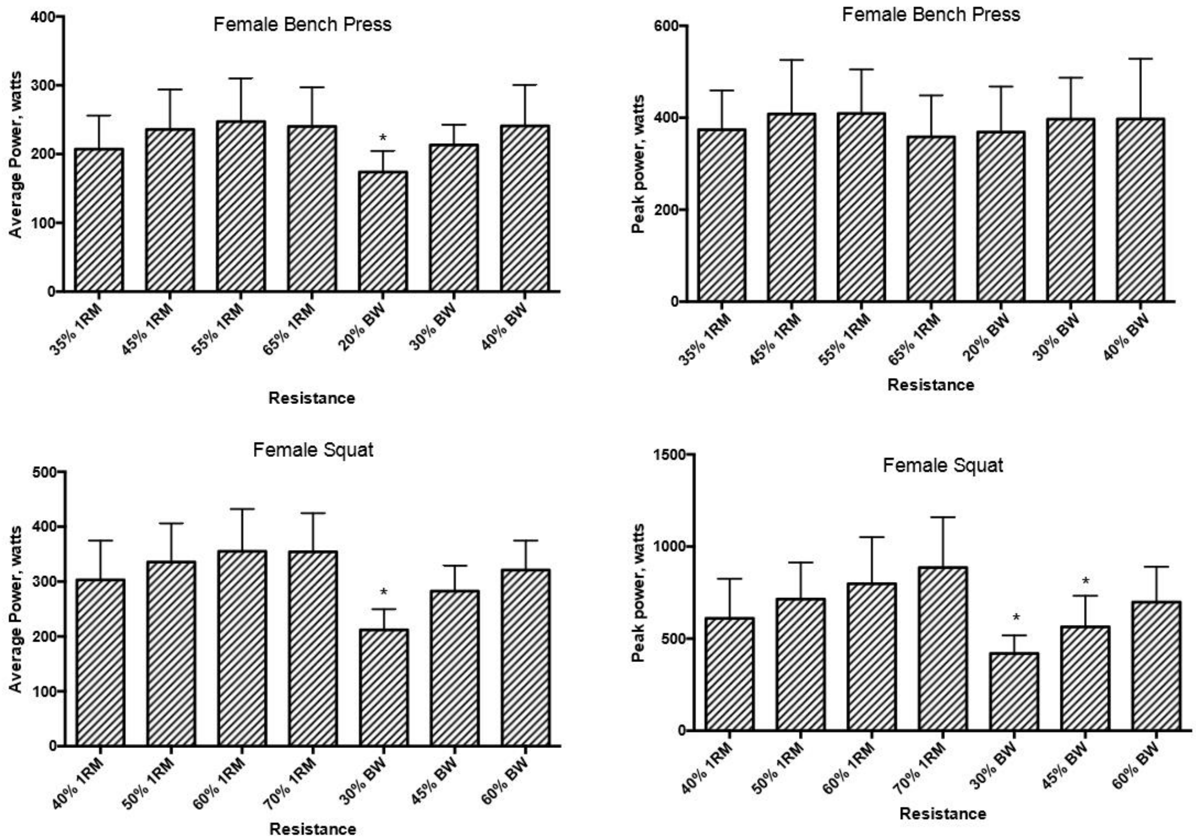

Figure 1a. Female Average and Peak Power outputs in the S and BP. * indicates significant difference in power outputs from the other tested intensities. 1RM = one rep max; BW = bodyweight.

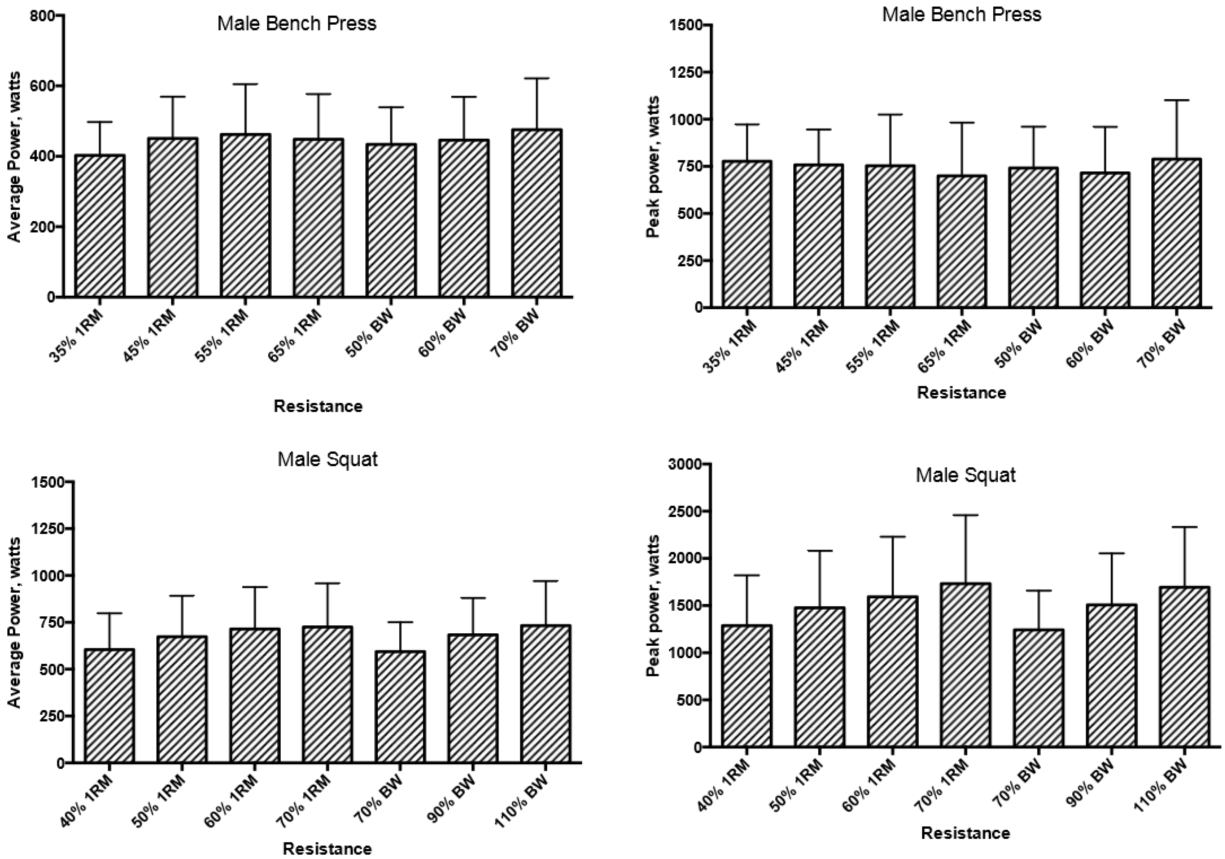

Figure 1b. Male Average and Peak Power outputs in the S and BP. 1RM = one rep max; BW = bodyweight.

Table 2. Subject Characteristics

	Male (n=18)	Female (n=10)
Age	19.9 ± 0.94	20.0 ± 1.18
Weight (kg)	86.4 ± 16.57	63.6 ± 7.10
Squat 1RM (kg)	141.1 ± 35.78	80.0 ± 13.96
Bench Press 1RM (kg)	96.5 ± 23.48	49.9 ± 11.83

Table 3. Intensities used in the study methods

Males		Females	
Squat	Bench Press	Squat	Bench Press
40% 1RM	35% 1RM	40% 1RM	35% 1RM
50% 1RM	45% 1RM	50% 1RM	45% 1RM
60% 1RM	55% 1RM	60% 1RM	55% 1RM
70% 1RM	65% 1RM	70% 1RM	65% 1RM
70% BW	50% BW	30% BW	20% BW
90% BW	60% BW	45% BW	30% BW
110% BW	70% BW	60% BW	40% BW

Table 4a. Female S variable means, standard deviations, and P values amongst the three trials/repetitions.

Females	Squat Load	Trial 1	Trial 2	Trial 3	P value
Average Power (watts)	40% 1RM	300.9 ± 55.3	303.1 ± 71.5	297.7 ± 67.4	0.98
Average Velocity (m/s)	40% 1RM	0.96 ± 0.09	0.96 ± 0.10	0.95 ± 0.10	0.90
Peak Power (watts)	40% 1RM	611.5 ± 226.7	610.4 ± 214.7	617.6 ± 232.4	0.99
Peak Velocity (m/s)	40% 1RM	1.49 ± 0.21	1.50 ± 0.20	1.50 ± 0.22	0.99
Average Power (watts)	50% 1RM	340.2 ± 70.0	335.7 ± 70.4	330.3 ± 67.3	0.95
Average Velocity (m/s)	50% 1RM	0.88 ± 0.06	0.86 ± 0.07	0.85 ± 0.09	0.79
Peak Power (watts)	50% 1RM	685.4 ± 223.5	714.4 ± 199.2	734.4 ± 235.8	0.88
Peak Velocity (m/s)	50% 1RM	1.38 ± 0.15	1.42 ± 0.12	1.43 ± 0.19	0.76
Average Power (watts)	60% 1RM	367.9 ± 66.3	355.2 ± 77.0	350.3 ± 71.7	0.85
Average Velocity (m/s)	60% 1RM	0.79 ± 0.06	0.77 ± 0.07	0.76 ± 0.07	0.60
Peak Power (watts)	60% 1RM	776.9 ± 223.4	797.9 ± 253.3	818.7 ± 238.6	0.93
Peak Velocity (m/s)	60% 1RM	1.31 ± 0.14	1.33 ± 0.15	1.36 ± 0.13	0.73
Average Power (watts)	70% 1RM	369.5 ± 92.0	354.1 ± 70.5	341.9 ± 69.9	0.73
Average Velocity (m/s)	70% 1RM	0.66 ± 0.10	0.64 ± 0.07	0.62 ± 0.08	0.50
Peak Power (watts)	70% 1RM	875.4 ± 249.5	886.0 ± 273.7	888.6 ± 243.22	0.99
Peak Velocity (m/s)	70% 1RM	1.25 ± 0.15	1.24 ± 0.13	1.25 ± 0.16	0.38
Average Power (watts)	30% BW	210.4 ± 37.6	211.9 ± 37.8	215.5 ± 34.4	0.95
Average Velocity (m/s)	30% BW	1.06 ± 0.14	1.12 ± 0.11	1.10 ± 0.11	0.53
Peak Power (watts)	30% BW	439.3 ± 156.7	419.7 ± 98.4	444.1 ± 105.1	0.90
Peak Velocity (m/s)	30% BW	1.70 ± 0.25	1.70 ± 0.19	1.73 ± 0.20	0.92
Average Power (watts)	45% BW	276.7 ± 39.3	282.7 ± 46.2	277.9 ± 44.1	0.95
Average Velocity (m/s)	45% BW	0.99 ± 0.11	1.02 ± 0.15	1.00 ± 0.12	0.92
Peak Power (watts)	45% BW	550.9 ± 133.5	563.9 ± 168.5	607.3 ± 167.9	0.71
Peak Velocity (m/s)	45% BW	1.54 ± 0.20	1.57 ± 0.25	1.61 ± 0.21	0.79
Average Power (watts)	60% BW	320.1 ± 50.2	320.9 ± 53.8	314.3 ± 51.3	0.95
Average Velocity (m/s)	60% BW	0.88 ± 0.12	0.88 ± 0.16	0.86 ± 0.15	0.96
Peak Power (watts)	60% BW	267.7 ± 48.0	261.8 ± 191.8	257.2 ± 199.3	0.96
Peak Velocity (m/s)	60% BW	1.41 ± 0.20	1.46 ± 0.22	1.44 ± 0.24	0.88

Table 4b. Female BP variable means, standard deviations, and P values amongst the three trials/repetitions.

Females	Bench Press Load	Trial 1	Trial 2	Trial 3	P value
Average Power (watts)	35% 1RM	191.7 ± 51.6	207.1 ± 49.0	212.9 ± 54.0	0.64
Average Velocity (m/s)	35% 1RM	1.1 ± 0.21	1.19 ± 0.12	1.21 ± 0.08	0.25
Peak Power (watts)	35% 1RM	383.8 ± 74.1	374 ± 85.3	384.6 ± 113.8	0.96
Peak Velocity (m/s)	35% 1RM	1.65 ± 0.25	1.63 ± 0.21	1.65 ± 0.15	0.97
Average Power (watts)	45% 1RM	225.3 ± 50.5	235.9 ± 58.0	222.2 ± 62.4	0.85
Average Velocity (m/s)	45% 1RM	1.05 ± 0.14	1.09 ± 0.12	1.04 ± 0.21	0.75
Peak Power (watts)	45% 1RM	384.8 ± 88.5	408.1 ± 117.5	407.4 ± 121.5	0.87
Peak Velocity (m/s)	45% 1RM	1.44 ± 0.21	1.48 ± 0.19	1.46 ± 0.18	0.89
Average Power (watts)	55% 1RM	234.2 ± 75.2	247.3 ± 62.7	246.3 ± 63.2	0.89
Average Velocity (m/s)	55% 1RM	0.91 ± 0.21	0.95 ± 0.10	0.95 ± 0.15	0.80
Peak Power (watts)	55% 1RM	392.3 ± 119.7	409.2 ± 95.9	405.9 ± 133.7	0.94
Peak Velocity (m/s)	55% 1RM	1.26 ± 0.21	1.26 ± 0.16	1.22 ± 0.21	0.88
Average Power (watts)	65% 1RM	234.8 ± 58.5	240.2 ± 56.9	231.8 ± 58.8	0.95
Average Velocity (m/s)	65% 1RM	0.76 ± 0.13	0.77 ± 0.08	0.74 ± 0.07	0.80
Peak Power (watts)	65% 1RM	345.8 ± 81.2	358.2 ± 90.4	350.4 ± 97.3	0.95
Peak Velocity (m/s)	65% 1RM	1.0 ± 0.17	1.0 ± 0.14	0.94 ± 0.12	0.48
Average Power (watts)	20% BW	175.8 ± 32.4	173.8 ± 30.7	186.8 ± 38.4	0.66
Average Velocity (m/s)	20% BW	1.28 ± 0.13	1.28 ± 0.15	1.37 ± 0.19	0.39
Peak Power (watts)	20% BW	382 ± 90.7	368.9 ± 98.8	424 ± 153.7	0.56
Peak Velocity (m/s)	20% BW	1.85 ± 0.20	1.83 ± 0.23	1.94 ± 0.23	0.50
Average Power (watts)	30% BW	191.6 ± 42.7	213.2 ± 29.4	209.1 ± 36.3	0.39
Average Velocity (m/s)	30% BW	1.03 ± 0.20	1.15 ± 0.17	1.12 ± 0.16	0.29
Peak Power (watts)	30% BW	362 ± 89.4	396.9 ± 90.3	373.4 ± 94.4	0.69
Peak Velocity (m/s)	30% BW	1.51 ± 0.27	1.57 ± 0.26	1.54 ± 0.26	0.88
Average Power (watts)	40% BW	241.3 ± 56.8	240.9 ± 59.5	248.4 ± 68.6	0.95
Average Velocity (m/s)	40% BW	0.98 ± 0.19	0.96 ± 0.19	0.99 ± 0.25	0.94
Peak Power (watts)	40% BW	401.7 ± 111.6	397.4 ± 130.9	415.8 ± 156.4	0.95
Peak Velocity (m/s)	40% BW	1.30 ± 0.25	1.27 ± 0.25	1.28 ± 0.32	0.97

Table 4c. Male S variable means, standard deviations, and P values amongst the three trials/repetitions.

Males	Squat Load	Trial 1	Trial 2	Trial 3	P value
Average Power (watts)	40% 1RM	594.9 ± 183.7	604.6 ± 193.7	601.1 ± 201.8	0.99
Average Velocity (m/s)	40% 1RM	1.07 ± 0.15	1.09 ± 0.12	1.07 ± 0.14	0.96
Peak Power (watts)	40% 1RM	1267.8 ± 496.9	1288.5 ± 532.6	1335.1 ± 549.7	0.93
Peak Velocity (m/s)	40% 1RM	1.71 ± 0.29	1.71 ± 0.26	1.72 ± 0.28	0.99
Average Power (watts)	50% 1RM	671.3 ± 222.2	673.2 ± 218.8	670.1 ± 207.6	0.99
Average Velocity (m/s)	50% 1RM	0.97 ± 0.14	0.97 ± 0.13	0.97 ± 0.13	0.99
Peak Power (watts)	50% 1RM	1445 ± 633.0	1477.1 ± 603.2	1515.2 ± 609.4	0.94
Peak Velocity (m/s)	50% 1RM	1.55 ± 0.29	1.58 ± 0.25	1.6 ± 0.24	0.87
Average Power (watts)	60% 1RM	723.8 ± 219.7	713.9 ± 224.5	706.3 ± 224.5	0.97
Average Velocity (m/s)	60% 1RM	0.87 ± 0.11	0.86 ± 0.11	0.85 ± 0.10	0.77
Peak Power (watts)	60% 1RM	1592.1 ± 609.8	1591.7 ± 638.6	1675.2 ± 706.9	0.91
Peak Velocity (m/s)	60% 1RM	1.46 ± 0.21	1.45 ± 0.26	1.5 ± 0.23	0.77
Average Power (watts)	70% 1RM	748.8 ± 226.7	725.5 ± 232.8	721.0 ± 236.8	0.93
Average Velocity (m/s)	70% 1RM	0.78 ± 0.11	0.75 ± 0.12	0.74 ± 0.12	0.65
Peak Power (watts)	70% 1RM	1723.2 ± 679.9	1732 ± 725.6	1823.4 ± 698.2	0.89
Peak Velocity (m/s)	70% 1RM	1.37 ± 0.22	1.37 ± 0.23	1.42 ± 0.22	0.70
Average Power (watts)	70% BW	592.2 ± 160.4	593.3 ± 157.7	604.8 ± 160.4	0.97
Average Velocity (m/s)	70% BW	1.01 ± 0.18	1.01 ± 0.18	1.03 ± 0.19	0.95
Peak Power (watts)	70% BW	1237.9 ± 429.0	1241.6 ± 415.6	1341.2 ± 442.1	0.72
Peak Velocity (m/s)	70% BW	1.62 ± 0.31	1.59 ± 0.30	1.67 ± 0.33	0.77
Average Power (watts)	90% BW	692.4 ± 207.9	683.7 ± 195.9	679.6 ± 195.0	0.98
Average Velocity (m/s)	90% BW	0.92 ± 0.20	0.91 ± 0.19	0.90 ± 0.19	0.97
Peak Power (watts)	90% BW	1534.7 ± 554.3	1507.8 ± 546.3	1555.2 ± 542.9	0.97
Peak Velocity (m/s)	90% BW	1.53 ± 0.32	1.51 ± 0.33	1.54 ± 0.32	0.97
Average Power (watts)	110% BW	757.1 ± 203.9	732.7 ± 237.3	705.4 ± 207.9	0.80
Average Velocity (m/s)	110% BW	0.81 ± 0.14	0.79 ± 0.19	0.76 ± 0.18	0.72
Peak Power (watts)	110% BW	1708.9 ± 563.9	1694.1 ± 638.2	1699.8 ± 564.2	0.99
Peak Velocity (m/s)	110% BW	1.42 ± 0.26	1.40 ± 0.32	1.40 ± 0.29	0.99

Table 4d. Male BP variable means, standard deviations, and P values amongst the three trials/repetitions.

Males	Bench Press Load	Trial 1	Trials 2	Trial 3	P value
Average Power (watts)	35% 1RM	384.6 ± 90.7	402.6 ± 95.0	416.6 ± 110.1	0.63
Average Velocity (m/s)	35% 1RM	1.17 ± 0.13	1.23 ± 0.18	1.26 ± 0.15	0.22
Peak Power (watts)	35% 1RM	726.4 ± 208.7	776.9 ± 195.5	794.7 ± 198.4	0.58
Peak Velocity (m/s)	35% 1RM	1.64 ± 0.20	1.71 ± 0.24	1.74 ± 0.20	0.36
Average Power (watts)	45% 1RM	437.4 ± 112.4	450.9 ± 118.6	447.9 ± 110.5	0.93
Average Velocity (m/s)	45% 1RM	1.03 ± 0.11	1.07 ± 0.13	1.07 ± 0.14	0.65
Peak Power (watts)	45% 1RM	770.28 ± 224.2	757.4 ± 188.3	771.1 ± 207.1	0.98
Peak Velocity (m/s)	45% 1RM	1.42 ± 0.19	1.44 ± 0.20	1.43 ± 0.21	0.97
Average Power (watts)	55% 1RM	453.4 ± 129.3	462.1 ± 142.8	454.6 ± 124.4	0.98
Average Velocity (m/s)	55% 1RM	0.87 ± 0.11	0.88 ± 0.12	0.87 ± 0.12	0.92
Peak Power (watts)	55% 1RM	710.5 ± 208.5	753.3 ± 272.0	751.4 ± 225.8	0.83
Peak Velocity (m/s)	55% 1RM	1.18 ± 0.18	1.17 ± 0.19	1.18 ± 0.17	0.99
Average Power (watts)	65% 1RM	456.2 ± 130.5	448.6 ± 127.9	436.7 ± 132.3	0.90
Average Velocity (m/s)	65% 1RM	0.75 ± 0.09	0.73 ± 0.10	0.72 ± 0.13	0.64
Peak Power (watts)	65% 1RM	736.0 ± 274.1	699.5 ± 283.2	701.6 ± 234.3	0.90
Peak Velocity (m/s)	65% 1RM	1.03 ± 0.21	0.96 ± 0.15	0.97 ± 0.15	0.51
Average Power (watts)	50% BW	418.9 ± 98.7	433.8 ± 105.4	441.2 ± 109.3	0.81
Average Velocity (m/s)	50% BW	1.0 ± 0.16	1.03 ± 0.17	1.05 ± 0.16	0.69
Peak Power (watts)	50% BW	779.2 ± 168.9	741.3 ± 219.5	764.9 ± 238.8	0.86
Peak Velocity (m/s)	50% BW	1.43 ± 0.23	1.43 ± 0.26	1.44 ± 0.25	0.99
Average Power (watts)	60% BW	440.8 ± 122.4	445.8 ± 123.0	432.6 ± 133.5	0.95
Average Velocity (m/s)	60% BW	0.88 ± 0.18	0.89 ± 0.19	0.86 ± 0.21	0.92
Peak Power (watts)	60% BW	710.9 ± 230.3	715.1 ± 244.1	708.8 ± 253.4	0.99
Peak Velocity (m/s)	60% BW	1.19 ± 0.24	1.18 ± 0.26	1.16 ± 0.25	0.94
Average Power (watts)	70% BW	472.3 ± 118.7	475.4 ± 146.2	431.1 ± 139.4	0.59
Average Velocity (m/s)	70% BW	0.81 ± 0.17	0.8 ± 0.22	0.73 ± 0.20	0.46
Peak Power (watts)	70% BW	805.9 ± 282.2	788.8 ± 313.0	717.3 ± 232.9	0.64
Peak Velocity (m/s)	70% BW	1.14 ± 0.30	1.07 ± 0.30	1.01 ± 0.26	0.41

Table 5a. Correlations between variables and 1RM in the S for females.

Correlation between variables and 1RM for **Females**	**Squat 40% 1RM**	**Squat 50% 1RM**	**Squat 60% 1RM**	**Squat 70% 1RM**	**Squat 30% BW**	**Squat 45% BW**	**Squat 60% BW**
AP							
r	0.903	0.917	0.883	0.867	0.26	0.646	0.726
R^2	0.816	0.841	0.779	0.752	0.07	0.418	0.527
SEE	6.69	6.23	7.32	7.77	15.05	11.91	10.74
Prob>[t]	0.0003	0.0002	0.007	0.0012	0.459	0.043	0.017
AV							
r	0.32	0.115	0.232	-0.017	0.389	0.789	0.792
R^2	0.102	0.013	0.054	0.0002	0.151	0.623	0.627
SEE	14.79	15.51	15.18	15.61	14.38	9.58	9.53
Prob>[t]	0.367	0.752	0.518	0.963	0.266	0.007	0.006
PP							
r	0.678	0.772	0.698	0.85	0.175	0.39	0.433
R^2	0.46	0.596	0.487	0.723	0.031	0.152	0.188
SEE	11.46	9.91	11.18	8.21	15.37	14.37	14.07
Prob>[t]	0.031	0.009	0.025	0.002	0.628	0.265	0.211
PV							
r	0.188	0.094	0.224	0.527	0.176	0.511	0.614
R^2	0.035	0.008	0.05	0.278	0.031	0.262	0.377
SEE	15.33	15.54	15.21	13.26	15.37	13.41	12.32
Prob>[t]	0.602	0.796	0.534	0.117	0.627	0.131	0.059

Values highlighted in yellow represent the highest correlation and lowest SEE of the %BW resistances. Values in red represent the highest correlation and lowest SEE of the %1RM resistances.

AP = average power; AV = average velocity; PP = peak power; PV = peak velocity; r = Pearson correlation coefficient; R^2 = coefficient of determination; SEE = standard error of estimate; Prob>[t] = two-tailed t-test results

Table 5b. Correlations between variables and 1RM in the BP for females.

Correlation between variables and 1RM for **Females**	Bench 35% 1RM	Bench 45% 1RM	Bench 55% 1RM	Bench 65% 1RM	Bench 20% BW	Bench 30% BW	Bench 40% BW
AP							
r	0.909	0.894	0.929	0.916	0.466	0.761	0.895
R^2	0.827	0.799	0.863	0.839	0.217	0.578	0.8
SEE	5.49	5.91	4.88	5.3	11.7	8.58	5.91
Prob>[t]	0.0003	0.0005	0.0001	0.0002	0.175	0.011	0.0005
AV							
r	-0.506	-0.222	-0.203	-0.346	0.351	0.376	0.815
R^2	0.256	0.049	0.041	0.119	0.123	0.141	0.664
SEE	11.4	12.89	12.95	12.41	12.38	12.25	7.65
Prob>[t]	0.135	0.538	0.574	0.327	0.319	0.284	0.004
PP							
r	0.795	0.844	0.775	0.843	0.591	0.705	0.838
R^2	0.631	0.712	0.602	0.711	0.35	0.497	0.702
SEE	8.02	7.09	8.34	7.1	10.62	9.38	7.21
Prob>[t]	0.006	0.002	0.008	0.002	0.072	0.023	0.002
PV							
r	-0.699	-0.521	-0.595	-0.553	0.178	0.324	0.646
R^2	0.489	0.271	0.354	0.306	0.032	0.105	0.418
SEE	9.45	11.28	10.62	11.01	13.01	12.5	10.09
Prob>[t]	0.024	0.122	0.069	0.097	0.622	0.36	0.043

Values highlighted in yellow represent the highest correlation and lowest SEE of the %BW resistances. Values in red represent the highest correlation and lowest SEE of the %1RM resistances.

AP = average power; AV = average velocity; PP = peak power; PV = peak velocity; r = Pearson correlation coefficient; R^2 = coefficient of determination; SEE = standard error of estimate; Prob>[t] = two-tailed t-test results

Table 5c. Correlations between variables and 1RM in the S for males.

Correlation between variables and 1RM for **Males**	**Squat 40% 1RM**	**Squat 50% 1RM**	**Squat 60% 1RM**	**Squat 70% 1RM**	**Squat 70% BW**	**Squat 90% BW**	**Squat 110% BW**
AP							
r	0.907	0.891	0.906	0.864	0.864	0.847	0.869
R^2	0.822	0.793	0.822	0.747	0.746	0.717	0.756
SEE	16.01	17.24	16.02	19.08	19.13	19.26	16.48
Prob>[t]	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
AV							
r	0.183	0.092	0.089	0.014	0.557	0.441	0.544
R^2	0.033	0.008	0.008	0.0001	0.31	0.195	0.296
SEE	37.31	37.79	37.8	37.95	31.52	32.53	27.98
Prob>[t]	0.467	0.716	0.726	0.957	0.016	0.076	0.029
PP							
r	0.752	0.758	0.726	0.776	0.727	0.743	0.749
R^2	0.566	0.574	0.527	0.603	0.529	0.551	0.56
SEE	25	24.77	26.08	23.9	26.04	24.27	22.1
Prob>[t]	0.0003	0.0003	0.0006	0.0001	0.0006	0.0006	0.0008
PV							
r	0.135	0.228	0.079	0.235	0.548	0.424	0.422
R^2	0.018	0.052	0.006	0.055	0.300	0.179	0.178
SEE	37.6	36.95	37.83	36.88	31.75	32.83	30.23
Prob>[t]	0.593	0.361	0.753	0.347	0.018	0.089	0.104

Values highlighted in yellow represent the highest correlation and lowest SEE of the %BW resistances. Values in red represent the highest correlation and lowest SEE of the %1RM resistances.

AP = average power; AV = average velocity; PP = peak power; PV = peak velocity; r = Pearson correlation coefficient; R^2 = coefficient of determination; SEE = standard error of estimate; Prob>[t] = two-tailed t-test results

Table 5d. Correlations between variables and 1RM in the BP for males.

Correlation between variables and 1RM for **Males**	**Bench 35% 1RM**	**Bench 45% 1RM**	**Bench 55% 1RM**	**Bench 65% 1RM**	**Bench50% BW**	**Bench 60% BW**	**Bench 70% BW**
AP							
r	0.848	0.876	0.875	0.838	0.815	0.864	0.799
R^2	0.718	0.768	0.765	0.703	0.664	0.746	0.638
SEE	13.21	11.99	12.07	13.58	14.43	12.54	13.64
Prob>[t]	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002
AV							
r	-0.402	-0.268	0.091	-0.118	0.433	0.528	0.492
R^2	0.161	0.072	0.008	0.014	0.187	0.278	0.242
SEE	22.81	23.99	24.8	24.73	22.45	21.15	19.75
Prob>[t]	0.098	0.282	0.72	0.641	0.073	0.024	0.053
PP							
r	0.224	0.658	0.746	0.586	0.703	0.792	0.626
R^2	0.05	0.433	0.556	0.343	0.494	0.611	0.392
SEE	24.27	18.75	16.59	20.18	17.71	15.52	17.68
Prob>[t]	0.372	0.003	0.0004	0.011	0.0011	0.0001	0.009
PV							
r	-0.513	-0.417	-0.145	-0.344	0.336	0.441	0.257
R^2	0.264	0.174	0.021	0.118	0.113	0.195	0.066
SEE	21.37	22.63	24.64	23.39	23.46	22.35	21.93
Prob>[t]	0.029	0.085	0.565	0.162	0.172	0.067	0.336

Values highlighted in yellow represent the highest correlation and lowest SEE of the %BW resistances. Values in red represent the highest correlation and lowest SEE of the %1RM resistances.

AP = average power; AV = average velocity; PP = peak power; PV = peak velocity; r = Pearson correlation coefficient; R^2 = coefficient of determination; SEE = standard error of estimate; Prob>[t] = two-tailed t-test results