RPE AND VELOCITY RELATIONSHIPS FOR THE BACK SQUAT, BENCH PRESS, AND DEADLIFT IN POWERLIFTERS

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ABSTRACT

Helms, ER, Storey, A, Cross, MR, Browm, SR, Lenetsky, S, Ramsay, H, Dillen, C, and Zourdos, MC. RPE and velocity relationships for the back squat, bench press, and deadlift in powerlifters. *J Strength Cond Res* 31(2): 292–297, 2017–The purpose of this study was to compare average concentric velocity (ACV) and rating of perceived exertion (RPE) based on repetitions in reserve on the squat, bench press, and deadlift. Fifteen powerlifters (3 women and 12 men, mean age 28.4 ± 8.5 years) worked up to a one repetition maximum (1RM) on each lift. Rating of perceived exertion was recorded on all sets, and the ACV was recorded for all sets performed at 80% of estimated 1RM and higher, up to 1RM. Rating of perceived exertion at 1RM on squat, bench press, and deadlift was 9.6 ± 0.5, 9.7 ± 0.4, and 9.6 ± 0.5, respectively and was not significantly different ($p > 0.05$). The ACV at 1RM on squat, bench press and deadlift was 0.23 ± 0.05, 0.10 ± 0.04, and 0.14 ± 0.05 $m \cdot second^{-1}$, respectively. Squat was faster than both bench press and deadlift ($p > 0.001$), and deadlift was faster than bench press ($p = 0.05$). Very strong relationships (r = 0.88–0.91) between percentage 1RM and RPE were observed on each lift. The ACV showed strong ($r = -0.79$ to -0.87) and very strong ($r = -0.90$ to 92) inverse relationships with RPE and percentage 1RM on each lift, respectively. We conclude that RPE may be a useful tool for prescribing intensity for squat, bench press, and deadlift in powerlifters, in addition to traditional methods such as percentage of 1RM. Despite high correlations between percentage 1RM and ACV, a "velocity load profile" should be developed to prescribe intensity on an individual basis with appropriate accuracy.

KEY WORDS rating of perceived exertion, repetitions in reserve, velocity based training, powerlifting, one repetition maximum, resistance training

INTRODUCTION

During a one-repetition maximum (1RM) test, the lifter has the cumbersome goal of reaching a limit lift while avoiding premature fatigue or attempting a load beyond their current capability. Specifically, in powerlifting (i.e., back squat, bench press, and deadlift), athletes are limited to 3 attempts on each lift and must wisely structure attempt selection to accomplish the described goal. Thus, using tools which gauge difficulty and aid in attempt selection are beneficial for the athlete.

Moreover, athletes have used rating of perceived exertion (RPE) to gauge effort for nearly 50 years (2); thus, this self-reported feedback can be used to alter training. Recently Zourdos et al. (18) developed a resistance training-specific RPE scale measuring repetitions in reserve (RIR), in which subjects provided an RPE value after a 1RM squat attempt. Additionally, the authors assessed average concentric velocity (ACV) during each 1RM attempt and used this in conjunction with RPE to determine each following attempt. The combination of these variables is thought by the authors to provide more accurate feedback than when used in isolation (18). Indeed, if lifting is performed at maximal intended velocity, decreasing concentric velocity can objectively determine greater intensity of effort (11,14). Importantly, in trained subjects Zourdos et al. (18) demonstrated a strong inverse relationship between average velocity during back squat and RPE ($r = -0.88$, $p < 0.001$) as a lifter approached 1RM (i.e., slower velocities at higher intensities correlated with higher RPE).

Despite the recent advancement of the RPE/RIR scale and its usage in conjunction with velocity to aid in back squat 1RM attempt selection; questions remain regarding the validity of

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31(2)/292–297

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these methods to determining bench press and deadlift 1RM. Therefore, the purpose of this study was to assess both RIR-based RPE (18) and average velocity in competitive male and female powerlifters, on all 3 powerlifts, in competition order and to determine any relationships between RPE and average velocity. It was hypothesized that resistance training-specific RPE would be an effective gauge of intensity in bench press and deadlift similar to previous data in squat (18); and that as RPE increased, average velocity would decrease.

Methods

Experimental Approach to the Problem

A 1RM testing session consisting of the powerlifting competition lifts (squat, bench press, and then deadlift) was completed. After each graduated increase in load, RPE as reported by the lifter and the corresponding velocities of the attempts were recorded. The resistance training-specific RPE scale based on RIR (18) was used. Briefly, this is a 1–10 RPE scale in which 10 is a maximal attempt, 9.5 indicates that a slight increase in load could have been made but no further repetitions could have been performed, a 9 indicates one more repetition could have been performed, 8.5 indicates 1–2 more repetitions, 8 indicates 2 more repetitions, and onward in that fashion.

Before 1RM testing, all subjects had their height and body mass measured and were interviewed to determine their age, training experience, competitive powerlifting experience, and competition results and what they believed their current 1RMs were on the competition lifts. After the interview, the subjects completed a standardized dynamic warm-up of body weight movements to prepare for the 1RM testing protocol. The 1RM testing consisted of successive sets progressing to maximal attempts for the barbell back squat, bench press, and deadlift performed according to the rules of the International Powerlifting Federation (IPF) (9). Subjects were prescribed a minimum of 3-minute and a maximum of 5-minute rest between lift attempts. The ACV and RPE were recorded on all lifts at ≥80% of predicted 1RM.

Subjects

Fifteen subjects (men: $n = 12$; women: $n = 3$) were recruited from powerlifting clubs and gyms in the local region (Table 1). To qualify for inclusion in the study, subjects had to have at least 1 year of resistance training experience and meet the national qualifying requirements for strength either in prior competition or during testing (12). Additionally, subjects had to abide by the banned substance list of the IPF (17), fall between the age range of 18–49 years, and be apparently healthy and free from injury or illness. All subjects were informed of potential risks and signed an informed consent document before participation (university ethics approval number 15/06).

Table 1. Descriptive characteristics of male and female powerlifters.*†‡

	Height (m)	Body mass (kg)	BMI (kg/m^2)	Age (y)	Training age (y)	Relative squat	Relative bench press	Relative deadlift
Females ($n = 3$)								
Mean ± *SD*	1.6 ± 0.1	59.0 ± 5.8	22.6 ± 1.4	36.0 ± 6.2	4.6 ± 1.6	1.6 ± 0.3	1.0 ± 0.1	2.1 ± 0.1
Males ($n = 12$)								
Mean ± *SD*	1.7 ± 0.1	87.9 ± 16.3	28.7 ± 3.1	26.5 ± 8.1	4.5 ± 3.1	2.3 ± 0.3	1.5 ± 0.2	2.7 ± 0.5
Combined ($n = 15$)								
Mean ± *SD*	1.7 ± 0.1	82.1 ± 18.9	27.5 ± 3.8	28.4 ± 8.5	4.5 ± 2.8	2.1 ± 0.4	1.4 ± 0.3	2.6 ± 0.5

*BMI = body mass index.
†Values are means ± *SD*.
‡Relative strength on squat, bench press, and deadlift presented as one repetition maximum divided by body mass.

Procedures

One Repetition Maximum (1RM). The 1RM testing protocol was administered after a standardized dynamic warm-up. Powerlifts were performed in competition order ([a] squat, [b] bench press, and [c] deadlift), and each lift was performed in accordance with IPF regulations using only IPF-approved "unequipped" lifting material aids (knee sleeves and weightlifting belt) (9). For the squat, participants had to reach a depth where the hip crease passed below the top of the knee when viewed from the lateral aspect. To signal the lifter to initiate squat, the verbal command "squat" was given and at the completion of the concentric phase the verbal command "rack" was given to signal the lifter to return the barbell to the squat rack. For bench press, the necessary contact points must have been maintained (head, upper back, buttocks, and feet flat), and once the bar was lowered to the chest, a verbal command of "press" was given once the primary investigator (previously a powerlifting referee and an experienced powerlifting coach) visually determined that the bar was motionless. Finally, the deadlift was deemed successful if upon lock out the body was fully erect, the bar did not travel downward in the course of the lift, and if at no time was the bar rested on the legs so that it aided the lifter. To signal the lifter to return the barbell to the floor, the verbal command "down" was given at the completion of the concentric phase.

To begin each lifting discipline, subjects first performed 8 repetitions with 50% of their estimated 1RM, followed by 3 repetitions at 60% of estimated 1RM, and 2 repetitions at 70% of estimated 1RM. Next, the subjects performed one repetition at 80% of estimated 1RM, followed by one repetition at 90% of their estimated 1RM. From this point, attempts were performed to achieve the highest load possible. The primary investigator used RPE score, ACV, and participant input to aid in determining subsequent attempts. A final 1RM was recorded if either a 10 RPE was reported by the subject or if an RPE score of less than 10 was reported but the lifter then failed to complete the next attempt with an increased load. If the lifter failed an attempt with an increased load, they were given the option to attempt it a second time. However, no decreases in load were allowed, and if the lift was missed a second time, the 1RM test for that lift was concluded. Once the final 1RM for a lift was recorded, the actual percentage of 1RM for all previous single-repetition sets was determined. For example, if the actual 1RM was 200 kg and the load for the 80% of predicted 1RM was 156 (based on a predicted 195 kg 1RM), the actual percentage of 1RM for this load would be 78%.

Rating of Perceived Exertion. Before 1RM testing began, the RPE scale was shown to the participant and verbally explained in the same manner as done by Zourdos et al. (18). Each value on the 1–10 scale was explained verbally along with a visual presentation of the scale that was visible throughout testing. Immediately after each warm-up and 1RM attempt, subjects were shown the RPE scale again and were asked to verbally rate the RPE of the set.

Average Concentric Velocity. All subjects had the ACV ($m \cdot second^{-1}$) of the barbell measured by the GymAware PowerTool (GymAware, Canberra, Australia) linear position transducer during all single repetition sets, which has been previously validated for test-retest reliability of barbell velocity (8). The GymAware was synced with a smart phone application that displayed the ACV of each repetition. The device was used according to the instructions of the manufacturers, so that when it was attached to the barbell, a perpendicular angle was achieved during all lifts.

Height, Body Mass, and Body Mass Index. Each participant had their height and body mass assessed (model 876; Seca, Germany). Furthermore, the body mass index (BMI) as determined by the equation $BMI = \frac{\text{body mass (kg)}}{\text{height (m}^2)}$ was recorded. The investigator who recorded all anthropometric variables was certified by the International Society for the Advancement of Kinanthropometry.

Statistical Analyses

Data were initially screened for outliers through visual assessment of the box plots, in association with the Shapiro-Wilks test for normality, and assessment of skewness and kurtosis values. One outlier case was determined as unreasonable and excluded from the raw data set. This decision was based on its magnitude (~×4 the standard deviation of the data set), and the case under which the result was reported (athlete returning to heavy training on the deadlift after minor injury months before the study start).

To express the potential range of values that could be reported by powerlifters based on our population sample, mean, *SD*, and 90% confidence limits (CLs) for RPE were calculated for all intensities. To determine differences in RPE scores at 1RM between squat, bench press, and deadlift a chi-square test was performed for nonparametric data, as an RPE score has a natural limit of 10. The velocity values from the maximal lifts of squat, bench press, and deadlift were compared using a mixed-models approach to repeated measures analysis in a statistical software package (IBM SPSS Statistics 21; SPSS Inc., Chicago, IL, USA). Bonferroni post-hoc adjustments were used for pairwise comparisons, with the alpha level for significance set at 0.05. Further comparisons between lifts were completed using magnitude-based inferences (1), calculated using a modified Excel spreadsheet from sportsci.org (*xPostOnlyCrossover.xls*) (6). The effect size and 90% confidence intervals (lower limit; upper limit) were calculated to compare the difference between each of the tested condition mean. Threshold values of 0.2, 0.6, 1.2, and 2.0 were used to represent small (and the smallest worthwhile difference), moderate, large, and

Table 2. Average concentric velocities and differences between lifts.*†‡§||

Lift: comparison	Mean ± *SD* ($m\cdot s^{-1}$)	Mean standardized difference ±90% CL (Cohen's)	*p*	Qualitative analysis of difference
Squat	0.23 ± 0.05			
vs bench press		2.41 ± 0.54	<0.001	Most likely, very large
vs deadlift		1.51 ± 0.46	<0.001	Most likely, large
Bench press	0.10 ± 0.04			
vs deadlift		0.80 ± 0.46	0.05	Very likely, moderate
Deadlift	0.14 ± 0.05			

*$m\cdot s^{-1}$ = meters per second.
†Values are mean ± *SD*.
‡Differences shown as standardized Cohen's effect size units ±90% confidence limits.
§Qualitative analysis of likelihood: possibly, 25–74%; likely, 75–94%; very likely, 95–99.5%; most likely, >99.5%.
||Qualitative analysis of effect size threshold: small, 0.2; moderate, 0.6; large, 1.2; very large, 2.0.

very large effects. Probabilities that differences were higher, lower, or similar to the smallest worthwhile difference were evaluated qualitatively as: possibly, 25–74.9%; likely, 75–94. 9%, very likely, 95–99.5%; and most likely, >99.5%. The true difference was assessed as unclear if the chance of both higher and lower values was >5%.

Correlation coefficient *r* scores and their associated *p* values were calculated to quantify the associations among ACV and RPE at all intensities and also actual percentage of 1RM and RPE. The coefficient of determination r^2 score was also calculated to express the explained variance of the correlation coefficients. The Excel spreadsheet from sportsci.org (*xvalid.xls*) (7) was used to plot the linear regression of the squat, bench, and deadlift data separately, where the percentage 1RM (ranging from 80–100%) was used as the criterion measure and the ACV of the lifts were used as the practical measure. By plotting the criterion (actual percentage 1RM) and practical measures (mean concentric velocity) in a linear regression model, a calibration equation was derived at which a percentage 1RM (y) could be predicted based on the measured ACV of a submaximal lift (x).

Table 3. Relationships between percentage of one repetition maximum and velocity.*

	Regression equation	Correlation (*r*)	Coefficient of determination (r^2)
Squat	y = −0.449x + 1.096	−0.91	0.83
Bench press	y = −0.600x + 1.051	−0.90	0.81
Deadlift	y = −0.600x + 1.076	−0.92	0.85

*x = measured average concentric velocity; y = predicted percentage of 1RM.

Results

Rating of Perceived Exertion

The mean and *SD*s for RPE on squat, bench press, and deadlift were 9.6 ± 0.5, 9.7 ± 0.4, and 9.6 ± 0.5, respectively. The values reported at 1RM for all 3 lifts were not significantly different ($p > 0.05$) from one another, and their 90% CLs almost completely overlapped (squat; 9.4–9.9, bench press; 9.5–9.8, and deadlift; 9.4–9.9).

Average Concentric Velocity

Mean, *SD*, and 90% CL for ACV for squat, bench press, and deadlift are provided in Table 2. As shown, velocities at 1RM were significantly different from one another with the squat occurring at the highest velocity, followed by the deadlift and bench press being the slowest.

Relationship of Average Concentric Velocity with Rating of Perceived Exertion

Strong inverse relationships between RPE and velocity were observed on squat ($r = -0.87$, $p < 0.001$), bench press ($r = -0.79$, $p < 0.001$), and deadlift ($r = -0.82$, $p < 0.001$). In squat, bench press, and deadlift, respectively, 76% ($r^2 = 0.76$), 63% ($r^2 = 0.63$), and 67% ($r^2 = 0.67$) of the variance of these correlations were attributable to the relationship between RPE and velocity.

Relationship of Actual Percentage of One Repetition Maximum with Rating of Perceived Exertion

Very strong relationships between actual percentage 1RM and RPE were observed on squat ($r = 0.91$, $p < 0.001$) and deadlift ($r = 0.91$, $p < 0.001$). A strong relationship was observed between actual percentage 1RM and RPE in bench press ($r = 0.88$, $p < 0.001$). In squat, bench press, and deadlift, respectively, 83% ($r^2 = 0.83$), 78% ($r^2 = 0.78$), and 83% ($r^2 = 0.83$) of the variance of these correlations were attributable to the relationship between actual percentage 1RM and RPE.

Relationship of Average Concentric Velocity with Actual Percentage of One Repetition Maximum

Very strong relationships between the ACV and percentage 1RM were observed on all 3 competition lifts. Pearson's correlations (r), coefficients of determination (r^2), and regression equations for the relationships between percentage of 1RM (80–100% only) and ACV are displayed in Table 3.

Discussion

The purpose of this investigation was to record the RPE and average velocity during all 1RM attempts of the squat, bench press, and deadlift in powerlifters. Our main findings were in support of our hypothesis and indicated: (a) RPE at 1RM reached near maximal scores (RPE 9.6–9.7) and (b) each individual discipline revealed a strong inverse correlation between average velocity and RPE ($r = -0.79$ to -0.87, $p < 0.001$). Similar findings exist for the squat (18); however, to our knowledge, this is the first investigation to examine both RIR-based RPE and velocity in 1RM bench press and deadlift testing.

Previous research using the Borg RPE scale to gauge intensity during a resistance training set has resulted in individuals recording submaximal RPE despite sets being performed to failure (5,13,16). However, in previous literature using the RIR-based RPE scale (18) and in the present investigation, trained lifters were able to accurately gauge intensity as evidenced by the strong and very strong relationships observed in this investigation between RPE and percentage 1RM ($r = 0.88$–0.91, $p < 0.001$) and velocity ($r = -0.79$ to 0.87, $p < 0.001$). Therefore, the present results suggest this RPE scale could be used to prescribe and alter training load (3) in all 3 powerlifts instead of solely relying on a percentage-based model. Prescribing RPE concurrently with percentage 1RM would allow the athlete to alter load dependent upon daily strength levels.

Similarly, the Zourdos et al. (18) RPE scale investigated here may be an attractive method to prescribe load because the validity of percentage 1RM prescription depends on an athlete's daily strength levels in comparison to the pretraining 1RM test (4). An athlete without extensive strength training experience can experience changes in their 1RM after only a few training sessions and the obtained 1RM may not accurately represent the athlete's true capability due to daily fluctuations in biological readiness and recovery (4,11). With that said, the RIR-based RPE scale does have limitations as previous data have shown experienced lifters to more accurately gauge RIR than novice lifters (18). Thus, previous training experience along with practice recording RPE while following a percentage-based program is recommended before solely using RPE to assign and progress training load. However, although RPE was a reliable gauge of intensity presently, velocity is likely a more objective assessment of intensity (4). Although daily strength will fluctuate, the inverse relationship between velocity and RPE will remain the same no matter what the fluctuation in strength might be (4,15).

Additionally, we explored the relationships between percentage 1RM and velocity for each lift. Owing to the strength of the present correlations between average velocity and load, we developed regression equations to predict 1RM based on velocity at intensities ≥80% (Table 3). To estimate 1RM using these equations, first ensure the load is expected to be at or above 80% of 1RM as this is what the regression is based on, then after repetition completion, enter the average velocity recorded and divide the barbell load used by the percentage provided. For example, if a 200-kg squat was recorded at $0.50\ \text{m}\cdot\text{second}^{-1}$, the equation would be: 200 kg/0.87 (87% of 1RM), which would estimate a 1RM of ~230 kg. Despite the strong relationship between average velocity and intensity, the practical application of the equations is limited as the 90% CL on all 3 regression equations amounts to a ±5% range on predicted percentage 1RM. For example, the 90% CL of the 1RM prediction for a 250-kg deadlift performed at a velocity of $0.25\ \text{m}\cdot\text{second}^{-1}$ provides a wide range of 257–284 kg. Thus, it appears an individualized velocity profile, which depends on a myriad of factors (i.e., limb lengths and training age) that would need to be determined to successfully prescribe training loads purely based on velocity (11). However, since we did not give specific instructions to lift at maximal intended velocity, it is possible that an equation based on participants who were given these instructions may have greater ability to predict 1RM.

The average velocity of the squat at 1RM presently ($0.23 \pm 0.05\ \text{m}\cdot\text{second}^{-1}$) was similar to the experienced lifters in Zourdos et al. (18) ($0.24 \pm 0.04\ \text{m}\cdot\text{second}^{-1}$). Previous data from Izquierdo et al. (10) has reported slightly faster velocity at squat 1RM ($0.27 \pm 0.02\ \text{m}\cdot\text{second}^{-1}$); however, these authors used "physically active" subjects, whereas our investigation and that by Zourdos et al. had an average training age of 4.5 and 5.2 years, respectively. Indeed, previous research has demonstrated experienced lifters to have slower velocities at 1RM than novice lifters (18). Similarly, the present bench press 1RM average velocity ($0.10 \pm 0.04\ \text{m}\cdot\text{second}^{-1}$) was slower than that of both Izquierdo et al. ($0.15 \pm 0.05\ \text{m}\cdot\text{second}^{-1}$) and Gonzalez-Badillo et al. ($0.16 \pm 0.04\ \text{m}\cdot\text{second}^{-1}$) (4,10), which used less-trained individuals. Regarding deadlift, the current study is the first to our knowledge to report average velocity at both 1RM and submaximal intensities; thus further research is needed to examine the relationship between training status and average velocity at specific intensities in the deadlift.

Practical Applications

Our investigation shows that the resistance training-specific RPE scale based on RIR produces nearly identical RPE values for all 3 lifts when performed up to and including 1RM. Therefore, this novel RPE scale can be used during 1RM testing to help gauge intensity with experienced lifters. To further aid 1RM testing on squat, bench press, and deadlift, the average concentric velocities at 1RM that we reported can be used as reference values to aid attempt selection. As velocity approaches the ranges we recorded at 1RM for each lift, smaller increases in load should be implemented so as to get as close as possible to a true 1RM.

Although velocity is an intriguing tool for load prescription, it most likely requires the development of individual velocity-load profiles before use. Rating of perceived exertion shows promise as a tool for trained lifters to gauge intensity on a regular basis without the need for a profile to be developed. It is possible that a combined approach of using percentage 1RM with a reference RPE range could prove a practical and accurate alternative to developing an individual velocity-load profile if the technology to do so is not available. The relationships between velocity, actual percentage of 1RM, and RPE all indicate that further study is needed to determine what the most effective way to prescribe and regulate resistance training intensity is.

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