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RELATIVE LOAD PREDICTION BY VELOCITY AND THE OMNI-RES 0-10 SCALE IN PARALLEL SQUAT

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ABSTRACT

This study analyzed the possibility of using movement velocity and the perceived exertion as predictors of relative load in the parallel squat exercise. In order to determine the full load-velocity and load-perceived exertion relationships, 290 young, resistance-trained athletes (209 male and 81 female) performed a progressive strength test up to the one-repetition maximum. Longitudinal regression models were used to predict the relative load from the average velocity and the OMNI-RES 0-10 scale, considering sets as the time-related variable. Two adjusted predictive equations were developed from the association between the relative load and the average velocity or the perceived exertion expressed after performing several sets of 1 to 3 repetitions during the progressive test. The resulting two models were capable of estimating the relative load with an accuracy of 79% and 86% for the average velocity [Relative load (% 1RM) = 120.15 – 83.54 (AV)] and the exertion [Relative load (% 1RM) = 5.07 + 9.63 (RPE)] respectively. The strong association between relative load with average velocity and the perceived exertion support the use of both predictive variables to estimate strength performance in parallel squat.

Key words: Strength test, perceived exertion, resistance training, one repetition maximum (1RM).

INTRODUCTION

The squat is one of the most popular core exercises utilized by athletes to enhance performance in sport (4). Many coaches in different disciplines consider the maximal strength (1RM) in squat as a reference criterion for assessing athlete's lower body conditioning and consequently designing resistance-training programs (25). Indeed, strong positive relationships have been reported between the 1RM in squat and specific athletic performance in soccer players (9) and endurance athletes (12). The most commonly applied methods for the evaluation of muscular strength are the one maximal repetition (1RM), defined as the maximum amount of weight that an individual could lift 1 time without support (26), and the multiple repetitions test (19). The latter uses prediction models derived from regression equations based on maximum number of repetitions performed in a set to failure with a submaximal load (15). Even though both methodologies have been extensively applied, from the practical point of view their administration is time-consuming and in some cases impracticable for large groups of athletes, such as team sports, making this method very difficult to apply on a regular basis during the training process (18). Consequently, alternative methodologies have been proposed to objectively assess strength performance in athletes. The possibility of using rotatory or linear position transducers to estimate velocity during resistance exercises involving mainly vertical displacement, allows researchers to have a better control of the exercise intensity (22). Furthermore, some previous investigations have considered the relationship between the movement velocity and the relative load (%1RM) to monitor changes in the ability to apply force in bench press (7, 11) and squat (1).

Bazuelo-Ruiz et al. (1) using a sample of novice participants, observed a good correlation between the 1RM and the mean displacement velocity achieved when squatting with a load equivalent to body weight. The reported relationship enabled the authors to construct an adjusted 1RM prediction model, which was capable of estimating the 1RM with an accuracy of 58%.

The aforementioned approaches require the use of additional devices (velocity transducers) that are not always available or require specific training conditions (almost purely vertical displacement of the used resistance), which are not suitable for all resistance-training exercises. Due to the impracticability of using these methods during each training session, researchers have sought easier methods to monitor resistance training. In recent years, perceived exertion scales have been successfully used to regulate resistance exercise intensities (6), monitor the progression of fatigue during workouts (13), estimate changes in the movement velocity or power within a singular set (22), and select the initial training load (14). Robertson et al. (24) developed prediction models, which used OMNI-Resistance Exercise Scales (OMNI-RES) to estimate 1RM for upper and lower body exercise. The scales have both verbal and mode specific pictorial descriptors distributed along a comparatively narrow numerical response range, 0–10. To the best of our knowledge, no study has analyzed and compared the accuracy of the two mentioned regression models, %1RM from mean velocity and %1RM from RPE, to estimate the relative load used during parallel squat in resistance-trained athletes. Thus, the purpose of the current investigation was to analyze and compare two regression models to predict %1RM, using the linear average velocity (AV) or the perceived exertion (RPE) to estimate the relative load in the concentric parallel squat (PSQ) in resistance-trained (female and male) athletes. Additionally, possible gender differences in the prediction model will also be analyzed.

METHODS

Experimental Approach to the Problem

Following a familiarization period of 12 to 15 sessions, participants performed a progressive PSQ strength test with increasing loads up to the 1RM for the individual determination of the full load-velocity and load-RPE relationships (21). Longitudinal regression models were constructed to predict the relative load in terms of %1RM from AV and RPE based on the best-fit regression line and considering sets as the time-related variable.

Subjects

Two hundred ninety young, healthy, resistance-trained athletes, 209 male (Mean ± SD: age = 25.4±5.6 y, height = 1.74±0.076 m, body mass = 73.8±9.2 kg, body mass index (BMI) = 24.2±1.9 $kg \cdot m^{-2}$) and 81 female (Mean ± SD: age = 20.1±4.1 y, height = 1.619±0.067 m, body mass = 59.83±6.3 kg, BMI = 22.8±2.0 kg/m^2), with a minimum of 1 and a maximum of 5 years of resistance training experience performing squatting exercises volunteered to take part in this study. All participants reported not having taken any banned substances as declared by the International Olympic Committee 2014 anti-doping rules (10). No physical limitations or musculoskeletal injuries that could affect strength performance were reported. The study met the ethical standards published by Harris and Atkinson (8) and was approved by the Institutional Review Board for Human Studies. After being informed of the purpose and experimental procedures, participants and/or parents or tutors signed a written informed consent form prior to participation.

Procedures

All 290 participants underwent a minimum of 12 familiarization sessions performed over a month (3 times per week) to use the OMNI-RES 0–10 scale proposed by Robertson et al. (24). The OMNI Scale for resistance exercises has both verbal and mode-specific pictorial descriptors distributed along a comparatively narrow response range of 0–10. These characteristics make the OMNI scale a useful methodology to control the intensity of resistance exercises (20).

During the familiarization period, the participants followed their normal resistance training workouts that comprised 2–4 sets of 6–12 repetitions of 6–8 exercises of different muscle groups (upper, middle, and lower body) including the squat. During these sessions, standard instructions, and RPE OMNI-RES 0-10 anchored procedures were explained to the participants in order to properly reflect the rating of perceived effort for the overall body (24) after performing the first and the last repetition in each set of every exercise (14, 22).

Progressive Test

All participants performed a progressive test (PRT) with increasing loads up to the 1RM for the individual determination of the full load-velocity and load-RPE relationships in the PSQ exercise.

The PSQ exercise was performed using free weights and a squat rack according to the technique described by Ratamess (23). Briefly, participants were instructed to start the exercise from standing, feet parallel and shoulder width apart with toes pointing slightly outward. The bar was either centered across the shoulders just below the spinose process of the C7 vertebra (high-bar position) (28). Participants were instructed to squat down using a controlled velocity until they reached the final flexed position with their posterior thigh parallel to the floor. After a minimum pause (less than 1 s.), aimed to provide a clear separation between repetitions (4), participants performed the concentric squatting phase in an explosive fashion, at maximum velocity. One qualified instructor controlled the appropriate range of motion during the squat exercise. The PRT was programmed in a way that allowed every participant to reach the 1RM in 8±2 sets of 2–3 repetitions. Each set was completed with the greatest possible force and had inter-set rest periods of 2–5 minutes, depending on the magnitude of the resistance to be overcome.

To determine the initial load of PRT, the first set was performed with approximately 15% of the estimated 1RM as agreed between participants and coaches after completing the familiarization period. Hence, the first and second sets were performed with very low external resistances (~15 and ~25% of the estimated 1RM), the third and fourth sets with light to moderate resistances (~35–45% of the estimated 1RM), the fifth and sixth sets with moderate resistances (~50–65% of estimated 1RM), and the seventh and eighth sets with heavy to maximum loads (>70% to 100% of the estimated 1RM). The repetition that produced the greatest AV at each set was selected for analysis. When the participant approached the estimated 1RM value, the rest periods between sets were prolonged to 5 minutes (18).

One Repetition Maximum Determination

If participants were able to perform more than 1 repetition on the eighth set of the PRT, they rested for 3–5 minutes before attempting another 1RM trial (5). All participants were able to achieve their 1RM within 1 or 2 additional trials (ninth and tenth set of the PRT).

OMNI-RES 0–10 scale instructions

Participants were instructed to report the RPE value indicating a number of the OMNI-RES 0–10 scale at the end of each set of the PRT. Participants were asked to use any number on the scale to rate their overall muscular effort, and the investigators used the same question each time: “how hard do you feel your muscles are working?” In our study, a rating of 0 was associated with no effort (seating or resting), and a rating of 1 was anchored with the perception of effort while lifting an extremely easy lifting (17). A rating of 10 was considered to be maximal effort and associated with the most stressful exercise ever performed (14). An experienced and certified strength and conditioning coach supervised all testing and recorded the RPE value at the end of all sets of the PRT. The OMNI–RES scale was in full view of participants at all times during the procedures.

Participants were asked to abstain from any unaccustomed or hard sets, including repetitions to failure, during the week before the test. Additionally, they agreed to not perform any exercise related to resistance training during the 72 hours preceding the PRT assessment session. Furthermore, the participants were instructed to maintain their regular diet and avoid caffeine ingestion for 48 h before the assessment session.

Equipment

An optical rotary encoder (Winlaborat®) with a minimum lower position register of 1 mm connected to the proprietary software Real Speed Version 4.20 was used for measuring the position and calculating the average velocity achieved during each repetition of the PSQ exercise. The cable of the encoder was connected to the bar in such a way that the exercise could be performed freely. The reliability of the PRT, including load sequences, velocity profile, and the OMNI-RES 0-10 scale values, was demonstrated in a series of previous pilot studies [intraclass correlation coefficients (ICC) >0.95]. For the present investigation, thirty participants were randomly selected to assess the repeatability of the measures provided by the PRT. The ICCs for the 1RM, AV, and RPE values were 0.95, 0.90 and 0.92 respectively.

Statistical Analysis

For each RPE value expressed immediately after performing a 1 to 3 repetitions set, the AV attained and % 1RM loads used in each set of the PRT were summarized as mean and 95% confidence intervals. Since each subject was assessed repeatedly, longitudinal regression models were used to predict the %1RM from AV and RPE, considering sets as the time-related variable. Three models were estimated for each predictor: pooled ordinary least squares (OLS) regression model, fixed-effects model, and random-effects model. Sex was added as a predictor for OLS and random-effects models but not for fixed effects models, as it is a time-invariant characteristic. A power analysis for the difference in slopes between male and female was performed. Hausman's specification test and the Breusch-Pagan Lagrange multiplier test were used to compare the consistency and efficiency of the models. Significance level was set at 0.05. Data analyses were performed with Stata 13.1 (StataCorp, College Station, TX).

RESULTS

The participants performed a median of 7 sets until 1RM was reached (Interquartile range [IQR]=7–8 for male, and IQR=6–8 for female). The maximum number of required sets was 10. In total, the 290 participants performed 2128 assessments. Maximum 1RM at PSQ was 108.7±23.1 kg and 65.9±13.0 kg for males and females respectively. The mean AV attained with the 1RM load for the total sample was 0.263±0.09 $m \cdot s^{-1}$, with very similar values observed for males (0.249±0.09 $m \cdot s^{-1}$) and females (0.299±0.10 $m \cdot s^{-1}$). The RPE value expressed by the participants after performing the last set (1RM) of the PRT was 10 in 85% of the sample, or 9.5 otherwise.

Relationship between relative load, RPE value, and average velocity

As shown in Table 1, relative load was around 13.5% when RPE was rated as 0, and 10 RPE was close to 1RM (~98.55%). Both males and females showed a similar relationship between RPE and relative load. An inverse relationship was shown between RPE and AV, as shown in Table 2, starting at ~1.24 $m \cdot s^{-1}$ for the 0 RPE value and declining gradually to ~0.26 $m \cdot s^{-1}$ for the 10 RPE value.

Tables 1 and 2

Table 3 shows fit of all regression models estimated to predict relative load from AV or RPE.

Table 3

The power analysis for the differences in regression slopes between male (1) and female (2) assuming a minimum difference of 0.015, a significance level of 0.05, n_1=209, n_2=81, SD_1=3.10, SD_2=2.82, and $SD_{residual}$=0.11, showed a 90.7% power for gender specificity of the models.

R-squared values were high and significant for the three models (Pooled OLS, fixed effects, and random effects) using AV to predict %1RM (R^2=0.79). The F-test for individual errors (u_i) was significant ($p<0.001$) and so was Breusch-Pagan test ($p<0.001$) for OLS vs. random effects. As shown in Table 3, Pooled OLS model showed also higher variance. Therefore, OLS model was less consistent and less efficient than fixed and random effects models for AV. Random effects model showed slightly higher R^2, along with a significant coefficient for sex. However, Hausman's test did not support significant differences between random and fixed effects models. Consequently, consistency and efficiency tests for AV models suggested the adoption of the fixed effects model. This model was able to explain 79% of overall variation in the relative load (%1RM), 4% of between-participants variation, and 90% of over-time (sets) variation. Therefore, the most appropriate equation (1) to estimate the relative load from AV was determined as:

(1) Relative load (% 1RM) = 120.15 – 83.54 (AV)

Similarly, RPE-based models predicted 86% of overall variation in relative load. F-test of individual errors was significant (p<0.001), Breush-Pagan LM test was significant (p<0.001), and SEE was higher for OLS model, supporting that OLS model was less appropriate. Fixed effects model explained 4% of between-participants variation and 93% of over-time (sets) variation. Additionally, the random effects model increased the explanation of between-participants variation up to 37% (Table 3). However, Hausman's test did not determine statistically significant differences to support the random effects model over the fixed effects model. Consequently, the following equation (2) is suggested to estimate the relative load from the RPE expressed at the end of each particular set from the random effects model:

(2) Relative load (% 1RM) = 5.07 + 9.63 (RPE)

DISCUSSION

The main findings of the present study were that both mean velocity attained with a given absolute load and the RPE values expressed immediately after performing 1–3 repetitions could be used as good predictors of the relative load (%1RM) in PSQ. The accuracy of the proposed methods in estimating the relative load in PSQ was 79% and 86% for the AV and RPE models respectively. Including gender as a predictor did not improve the accuracy of the models; therefore, its inclusion would not be necessary.

To the best of the authors' knowledge, this is the first study to analyze the association between load with the AV and the perceived exertion and its suitability to predict the relative load in parallel squat exercise using resistance-trained individuals. Bazuelo-

Ruiz et al. (1) proposed a regression model to predict the 1RM in squat based on the mean velocity at which an external weight equal to body mass was lifted during the concentric phase in half squat. The accuracy of the method was 58%. Consistent with the AV model calculated in our study, the accuracy of the aforementioned model was not improved by the addition of gender. However, the authors highlight that although no improvement in 1RM prediction was found after the inclusion of the gender variable, the obtained coefficient was close to significant (p=0.10). Bazuelo-Ruiz et al. used untrained participants who squatted against a load equivalent to their body weight, and that load represented a ~9% higher %1RM in women compared with men. Conversely, participants in our study were resistance-trained individuals with a minimum of 1 year of experience performing squat; consequently, regardless of the sex, they would be able to exhibit a better ability to produce and maintain greater force at higher relative movement velocity, resulting in a differed pattern of force/velocity curve compared to weaker or untrained individuals (16).

Although several regression equations based on the number of repetitions performed to failure using submaximal weights have been proposed to predict the relative load or the 1RM in different exercises (15) including squat (2), their application still remains controversial. Ware et al. (27) reported moderately to large errors of Bryzcki, Epley, Lander, and Mayhew equations at predicting squat performance in college football players. Similar to the 1RM test, the multiple repetition protocols represent a maximal effort leading to high muscular, bone, and ligament stress, triggering important metabolic alterations (3). The impact of such maximal assessment sessions should be considered when designing the whole training program within a periodized approach. Both models resulting from the present study would allow coaches to have a relatively good estimation of the strength performance variation after only 1 set of 1–3 repetitions performed with a maximal possible velocity and using a submaximal load. The proposed methodology would help athletes to avoid long testing sessions involving high levels of neuromuscular stress that in turn would interfere with other training activities.

Although both proposed methodologies (AV and RPE) presented in this current investigation seem to be accurate with acceptable errors of estimation, 9.82% and 8.17% for the AV and RPE model respectively (Table 3), the RPE method is slightly more accurate than the AV model. The ability of perceived exertion for estimating the relative load (%1RM) and discriminating between different resistance training intensities has been previously demonstrated (14, 26). Lagally et al. (14) tested the application of RPE derived from the OMNI-RES (0-10) metric to select the initial training load associated with specific resistance training outcomes: muscle endurance (RPE ~3), hypertrophy (RPE ~ 6), and maximal strength (RPE ~9) training outcomes. However, in order to reduce inter-individual differences in the interpretation of the scale resulting from subjective perceptions of exercise intensities and the anchored procedures between the RPE values and the perceived effort, the application of perception scales have to be preceded by a proper familiarization period. In the present study, participants were highly adapted and familiarized with the use of RPE OMNI-RES (0-10) metric. All participants used the scale for controlling their resistance-training routines for a minimum of 12 sessions. Consequently, it seems that, at least for resistance-trained exercisers who have followed an appropriate period of familiarization, the use of perceived exertion scales could represent an accurate, easy, practical, and economic alternative for controlling performance variation in daily workouts throughout the training process.

Results of the present study provide two useful predictive mixed sample (male and female) models to estimate the %1RM from a multiple linear regression fitting. In these models the load lifted and the corresponding AV or the estimated RPE values were able to explain 79% and 86% of the predicted %1RM respectively. Both models would facilitate a follow up of the performance fluctuation; consequently, a training program could then be easily modified according to the present day's performance level. Although the RPE method demands a period of familiarization, it entails a useful and simple approach for evaluating strength in a large population of athletes. From the practical point of view, according to the completed model (Table 3), for each 0.1 $m \cdot s^{-1}$ increase in barbell velocity achieved with a given weight, the corresponding relative load (%1RM) will decrease by about 8.35%. On the other hand, for each decrease in the RPE value expressed after performing a set of 1-3 repetitions, the relative load corresponding to the used weight will decrease by 9.63%. In conclusion, results from the present study demonstrate a strong relationship between the load and the two analyzed variables (AV and the RPE) measured during or at the end of a 1–3 repetitions set over a wide range of intensities (from ~15% to 100% 1RM) of parallel squat exercise. However, further research will be necessary to assess the validity and accuracy of the both proposed prediction models.

PRACTICAL APPLICATION

The present results support the utility of the AV and/or RPE determined in a single 1 to 3 repetitions set with a submaximal load to predict the relative load used by male and female resistance-trained athletes in parallel squat using free weights. The proposed methodologies would allow a continuous control of the strength performance fluctuation over the training process. Although the SEE shows a slightly more accurate value for the RPE compared to AV model, both methods seem to be accurate enough and would provide a practical and reliable estimation of the relative load used during parallel squat in resistance-trained individuals.

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Competing interests:

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TABLES

Table 1. Mean and 95% confidence interval of %1RM corresponding to each RPE score for male (n=209), female (n=81), and total (n=290).

	Male			Female			Total sample		
RPE	n	Mean	95% CI	n	Mean	95% CI	n	Mean	95% CI
0	100	13.30	(12.2 – 14.4)	7	16.31	(14.9 – 17.7)	107	13.49	(12.4 – 14.6)
1	95	21.06	(18.6 – 23.5)	29	18.36	(16.2 – 20.5)	124	20.43	(18.5 – 22.4)
2	141	25.29	(22.8 – 27.8)	46	23.45	(20.9 – 26.0)	187	24.84	(22.9 – 26.8)
3	161	34.60	(32.4 – 36.8)	67	30.28	(27.9 – 32.7)	228	33.33	(31.6 – 35.1)
4	123	42.74	(40.1 – 45.4)	60	40.47	(37.5 – 43.5)	183	41.99	(40.0 – 44.0)
5	135	50.80	(48.5 – 53.1)	61	54.32	(51.6 – 57.0)	196	51.88	(50.1 – 53.7)
6	152	61.92	(59.8 – 64.0)	58	63.68	(60.9 – 66.4)	210	62.41	(60.7 – 64.1)
7	155	71.25	(69.4 – 73.1)	58	73.13	(70.4 – 75.9)	213	71.76	(70.2 – 73.3)
8	153	82.66	(80.9 – 84.4)	54	84.16	(82.2 – 86.1)	207	83.05	(81.7 – 84.4)
9	129	88.67	(86.9 – 90.4)	35	87.80	(85.8 – 89.8)	164	88.49	(87.1 – 89.9)
10	221	98.43	(97.3 – 99.6)	88	98.58	(97.7 – 99.4)	309	98.47	(97.6 – 99.3)

RPE=rate of perceived exertion with OMNI RES 0-10 scale.

Table 2. Mean and 95% confidence interval of AV (m·s^{-1}) corresponding to each RPE score for male (n=209), female (n=81), and total (n=290).

	Male			Female			Total		
RPE	n	Mean	95% CI	n	Mean	95% CI	n	Mean	95% CI
0	100	1.24	(1.19 – 1.29)	7	1.18	(1.06 – 1.30)	107	1.24	(1.19 – 1.28)
1	95	1.12	(1.08 – 1.17)	29	1.20	(1.14 – 1.26)	124	1.14	(1.10 – 1.18)
2	141	1.06	(1.02 – 1.10)	46	1.24	(1.17 – 1.31)	187	1.11	(1.07 – 1.14)
3	161	0.98	(0.95 – 1.01)	67	1.11	(1.06 – 1.15)	228	1.01	(0.99 – 1.04)
4	123	0.88	(0.84 – 0.91)	60	0.99	(0.94 – 1.03)	183	0.91	(0.88 – 0.94)
5	135	0.80	(0.77 – 0.83)	61	0.84	(0.79 – 0.89)	196	0.81	(0.79 – 0.84)
6	152	0.69	(0.66 – 0.73)	58	0.74	(0.69 – 0.79)	210	0.71	(0.68 – 0.73)
7	155	0.60	(0.57 – 0.63)	58	0.65	(0.60 – 0.69)	213	0.61	(0.59 – 0.64)
8	153	0.48	(0.45 – 0.50)	54	0.53	(0.48 – 0.58)	207	0.49	(0.47 – 0.51)
9	129	0.40	(0.38 – 0.42)	35	0.48	(0.43 – 0.52)	164	0.42	(0.40 – 0.44)
10	221	0.25	(0.24 – 0.26)	88	0.30	(0.28 – 0.32)	309	0.26	(0.25 – 0.27)

Table 3. Fit of regression models predicting relative load (%1RM) from AV and RPE (n=290).

	Constant		AV		RPE		Sex		Model				
	B_0	p	B_{AV}	p	B_{RPE}	p	B_{SEX}	p	p	R^2	R^2_{btw}	R^2_{with}	SEE
AV													
Pooled OLS	106.20	<0.001	–74.41	<0.001			5.71	<0.001	<0.001	0.79			10.67
Fixed effects	120.15	<0.001	–83.54	<0.001					<0.001	0.78	0.04	0.90	9.82
Random effects	109.31	<0.001	–78.83	<0.001			5.77	<0.001	<0.001	0.79	0.06	0.90	9.82
RPE													
Pooled OLS	8.56	<0.001			9.11	<0.001	–0.49	0.373	<0.001	0.86			11.23
Fixed effects	5.07	<0.001			9.63	<0.001			<0.001	0.86	0.04	0.93	8.17
Random effects	6.98	<0.001			9.45	<0.001	–0.70	0.354	<0.001	0.86	0.37	0.93	8.17

AV=average velocity ($m \cdot s^{1}$); RPE=rate of perceived exertion with OMNI RES (0–10) scale; sex (female). P values are shown for each coefficient and for the model adjustment. R^2=overall adjustment of the model; R^2_{btw}=variation due to individual differences; R^2_{with}=variation due to over-time differences, SEE=Standard Error of Estimate.