LOADING INTENSITY PREDICTION BY VELOCITY AND THE OMNI-RES 0-10 SCALE IN BENCH PRESS

ABSTRACT

This study examined the possibility of using movement velocity and the perceived exertion as indicators of relative load in the bench press exercise. Three hundred eight young, healthy, resistance trained athletes (242 male and 66 female) performed a progressive strength test up to the one-repetition maximum for the individual determination of the full load-velocity and load-exertion relationships. 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. Load associated with the average velocity and the OMNI-RES 0-10 scale value expressed after performing a set of 1-3 repetitions were used to construct two adjusted predictive equations: Relative load = 107.75 – 62.97 × average velocity; and Relative load = 29.03 + 7.26 × OMNI-RES 0-10 scale value. The two models were capable of estimating the relative load with an accuracy of 84% and 93% respectively. These findings confirm the ability of the two calculated regression models, using load-velocity and load-exertion from the OMNI-RES 0-10 scale, to accurately predict strength performance in bench press.

Key words: Strength assessment, resistance training, isoinertial estimation, perceived exertion.

INTRODUCTION

The determination of an individual's maximal strength has been a key factor in prescribing and regulating resistance training programs (8). The most commonly applied methods for the evaluation of muscular strength are the one maximal repetition (1RM) and the multiple repetitions test (20). The latest uses prediction models for 1RM derived from regression equations based on maximum number of repetitions performed in a set to failure with a submaximal load (18). The 1RM test, despite being one of the most widely used and frequently mentioned tests in the literature, has been associated with some weaknesses; e.g. it requires considerable time in the preparation for the testing session but also some prior knowledge of the performance technique when reaching a maximal effort (20, 29), Moreover the administration is time consuming and impracticable to use in large groups of athletes, making this method very difficult to apply on a regular basis during the training process (19). On the other hand, multiple repetition tests have been described as safer (4) and therefore much more applicable to certain populations such as young, older or with pre-existing medical conditions (25). Although multiple repetition tests are performed with submaximal loads, in the end they would also represent a maximal effort that may lead to high muscular, bone, and ligament stress, triggering important metabolic alterations (5). The aforementioned limitations of repetition maximum tests have lead coaches and researchers to seek alternative methods to objectively monitor performance progression during resistance training. The recently increasing use of devices such as accelerometers, rotatory or linear position transducers capable of calculating velocity during resistance exercises, allows estimating the 1RM and the relative training loads from the relationship between the movement velocity and the relative load (%1RM) (11, 15).

Gonzalez-Badillo and Sanchez-Medina (11) reported very close relationships (R^2=0.98) between both, mean accelerative velocity (calculated from the accelerative portion of the concentric phase, during which the acceleration of the barbell was ≥ -9.81 m·s^{-2}), and mean velocity with the %1RM used during a Smith machine bench press in 120 resistance trained young men. Similarly, Jidovtseff et al. (15) analyzed data from 112 recreationally active participants (90 males, 22 females) to establish a similarly high correlation (r=0.95) of the load-velocity relationship to accurately predict bench press 1RM. These studies rely on the strong association between the movement velocity and the training load, to monitor changes in the ability to apply force in resistance exercises. However, the aforementioned approach requires the use of additional devices (accelerometers or 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 (10), monitor the progression of fatigue during workouts (16), estimate changes in the movement velocity or power within a singular set (23), and select the initial training load (17). Robertson et al. developed prediction models, which use OMNI-Resistance

Exercise Scales (OMNI-RES) derived from adults (27) or children (26) format 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. More recently, Bautista et al. (2) proposed a regression model to predict the mean bar velocity from the RPE OMNI RES 0-10 scale for the bench press. To the best of our knowledge, no study has analyzed and compared the accuracy of the two mentioned regression models, mean velocity-%1RM and RPE-%1RM, to estimate the relative load used during bench press exercise. Thus, the purpose of this study 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 bench press (BP) 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 an isoinertial progressive bench press strength test with increasing loads up to the 1RM for the individual determination of the full load-velocity and load-RPE relationships (22). 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

Three hundred eight young, healthy, resistance trained athletes, 242 male (Mean ± SD: age = 22.4±7.7 y, height = 1.749±0.074 m, body mass = 73.3±10.4 kg, body mass index (BMI) = 23.9±2.2 $kg·m^{-2}$) and 66 female (Mean ± SD: age = 19.1±5.5 y, height = 11.602±0.054 m, body mass = 57.5±5.7 kg, BMI = 22.4±2.0 kg/m^2), with a minimum of 1 and a maximum of 5 years of resistance training experience performing bench press 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 (14). No physical limitations or musculoskeletal injuries that could affect strength performance were reported. The study met the ethical standards published by Harris and Atkinson (12) 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 308 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. (27). 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 training (21).

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 bench press. During these sessions, standard instructions, and RPE OMNI-RES 0-10 anchored procedures were explained to the participant in order to properly reflect the rating of perceived effort for the overall body (27) after performing the first and the last repetition in each set of every exercise (17, 23).

Progressive Test

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

The flat BP exercise was performed using Olympic bars and discs according to the technique described by Baechle et al. (1). Briefly, participants were instructed to start the exercise lying down on a bench with their elbows fully extended and to lower the bar towards the chest using a controlled velocity. After a minimum pause (less than 1 s.), participants performed the concentric phase in an explosive fashion, at maximum velocity. 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

30% of the estimated 1RM as agreed between participants and coaches after completing the familiarization period. Hence, the first and second sets were performed with low resistance (~30 and ~45% of the estimated 1RM), the third and fourth sets with light to moderate resistance (~50–65% of the estimated 1RM), the fifth and sixth sets with medium-high resistance (~70–80% of estimated 1RM), and the seventh and eighth sets with maximum or near maximum load (~85–100% of the estimated 1RM). The repetition that produced the greatest average velocity (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 (19).

One Repetition Maximum Determination

If participants were able to perform more than 1 repetition on the last set of the PRT, they rested for 3–5 minutes before attempting another 1RM trial (9). All participants were able to achieve their 1RM within 1 or 3 trials.

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, ‘‘how hard do you feel your muscles are working,’’ each time. A rating of 0 was associated with no effort (rest), and a rating of 10 was considered to be maximal effort and associated with the most stressful exercise ever performed (17). 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 committed to not perform any resistance training related exercise during the 72 hours preceding the PRT assessment session.

Equipment

An optical rotary encoder (Tesys 400, Globus Corporation, Codgne, Italy) with a minimum lower position register of 1 mm was used for measuring the position and calculating the velocity, force, and power applied during each repetition of the BP exercise. The cable of the encoder was connected to the bar in such a way that the exercise could be performed freely. The encoder's method of functioning enabled the cable to move in either vertical direction of the movement, sending the position of the bar every millisecond (1,000 Hz) to an interface that was connected to a computer. Proprietary software for the encoder (Ergo System, version 8.5) was used to calculate the AV in $m{\cdot}s^{-1}$ during the concentric phase. The reliability of the PRT was demonstrated in a series of previous pilot studies [intraclass correlation coefficients (ICC) >0.92]. 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 0.99; 0.89 and 0.96 respectively.

Statistical Analysis

The AV attained with a given range of % 1RM loads used in each set of the PRT was summarized as mean and 95% confidence intervals for each RPE value expressed immediately after performing a 1 to 3 repetitions set. 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

Median number of sets performed by each participant until 1RM was reached was 8 (Interquartile range [IQR]=7-8) for male, and 6 (IQR=5-7) for female. In total, 2222 assessments were performed. Maximum 1RM values for the BP exercise for males and females were 84.5±24.2 kg and 40.3±8.3 kg respectively. The mean average velocity attained with the 1RM load for the total sample was 0.165±0.07 $m{\cdot}s^{-1}$, with very similar values observed for males (0.162±0.07 $m{\cdot}s^{-1}$) and females (0.175±0.08 $m{\cdot}s^{-1}$). The RPE value expressed by the participants after performing the last set (1RM) of the PRT was 10.

Relationship between relative load, RPE value, and average velocity

As shown in Table 1, relative load was below 30% when RPE was rated as 0, and 1RM corresponded to 10 RPE. 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 ~1.25 $m \cdot s^{-1}$ for the 0 RPE value and declining gradually to ~0.24 $m \cdot s^{-1}$ 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/female assuming a minimum difference of 0.015, a significance level of 0.05, n_1=222, n_2=66, SD_1=3.39, SD_2=3.27, and $SD_{residual}$=0.06, showed a 99.97% 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=0.84). 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 efficient than fixed and random effects models for AV. Random effects model did not show a significant coefficient for sex, and additionally 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 84% of overall variation in the relative load (%1RM), 24% of between-participants variation and 92% 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) = 107.75 – 62.97 (AV)

Similarly, RPE-based models predicted 93% 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 35% of between-participants variation, and 96% 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 determined no significant difference between fixed and random models. 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 fixed effects model:

(2) Relative load (% 1RM) = 29.03 + 7.26 (RPE)

DISCUSSION

The main findings of this study were that both mean velocity attained with a given absolute load and the RPE values expressed immediately after performing 1–3 repetitions would be used as very good predictors of the relative load (%1RM).

The accuracy of the proposed methods in estimating the relative load in bench press was 84% and 93% for the AV and RPE models respectively. Including gender as a predictor did not significantly improve the models. Therefore, its inclusion would not be necessary to increase the accuracy of predictive models using AV or RPE.

Previous investigations (11, 15) have also analyzed the relationship between relative load and velocity in bench press. Gonzalez-Badillo and Sanchez-Medina (11) found a close polynomial relationship between the relative load (%1RM) and mean velocity (R^2=0.979; $p<0.05$) measured over the entire concentric phase, or mean accelerative velocity (R^2=0.98; $p<0.05$). Gonzalez-Badillo and Sanchez-Medina (11) included more than one assessment per each load-velocity measurement per participant. This approach may have overestimated the data fit due to the presence of auto-correlation. When more than one observation is used from the same participant to calculate the load-velocity relationship, the observations can no longer be independent and the resulting R^2 will be inflated (3, 24). Thus, with the aim of preventing calculation bias, data from the present study were analyzed assuming different assessments per participant (~8 on average) as related measures. A longitudinal analysis of the assessments was considered the most accurate model.

Jidovtseff et al. reported a very high correlation (r≈0.95) between the estimated theoretical load at zero velocity (maximal isometric strength) and the 1RM in bench press (15). The estimation was extrapolated from a regression equation calculated from a minimum of three average velocities and the corresponding %1RM loads. Although this is a very practical and easy approach to estimate the 1RM value, the model presented by Jidovtseff et al. (15) requires a minimum of 3 incremental loads whilst our model would be able to predict the relative load from only 1 set of up to three repetitions using a constant submaximal load, performed at a maximum velocity.

Although both proposed models (AV and RPE) presented in this current investigation seem to be very accurate with acceptable errors of estimations (7.22% and 5.07% for the AV and RPE model respectively (Table 3), the RPE method is slightly more accurate than the AV model. Several factors could have caused this result. Different from the studies mentioned above (11, 15) in which the BP exercise was performed using a Smith Machine, which ensures a smooth, controlled, purely vertical displacement of the bar along a fixed pathway. In contrast our investigation used free weights. Performing resistance exercises with free weight increases the horizontal displacement of the bar and consequently increases the potential error of a transducer device in estimating the vertical velocity. Although, this factor would represent a limitation of our study, the ability of the velocity transducers to provide valid measures of kinetics during free weight resistance exercises in well-trained athletes has been previously demonstrated (6) and supported in several other investigations (13, 23).

In addition, our study also analyzed the predictive power of the perceived exercise model using the RPE OMNI-RES 0-10 scale (27). Bautista et al. (2) reported a strong correlation (r = –0.94) between RPE values and mean bar velocity during bench press. This study supported the utility of the perceived exertion for predicting bar velocities using RPE values derived from the OMNI–RES 0-10 scale.

The use of perceived exertion for estimating the relative load (%1RM) in resistance exercises has been previously analyzed. Lagally et al. (17) tested the application of RPE derived from the OMNI-RES (0-10) metric to select the initial training load associated with specific, muscle endurance, and maximal strength training outcomes. More recently, Naclerio et al. (21) suggested that the initial RPE could be used to select the %1RM load associated with the pre-determined resistance training outcomes: maximal strength (RPE > 7 to ~9), hypertrophy or explosive strength with moderate load (RPE > 3 to ~7), or muscle endurance or explosive strength with light load (RPE > 0 to ~3). 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 the OMNI-RES 0-10 scale has to be preceded by a well-supervised familiarization period. It has been highlighted that in order to properly regulate resistance exercise intensity using RPE scales, coaches need to differentiate overall RPE that reflects general fatigue of the body, from the active muscle RPE that express the perception of effort focused on specific body areas (10). Although both rating types have shown to be valid for controlling resistance training, they would produce significantly different values (7). Therefore, in our study we specifically analyzed one upper body exercise; we used the overall RPE procedure because our participants were familiarized with this approach during workouts involving several exercises. From this point of view, the overall RPE procedures following standard and clear instructions would be more applicable to a range of resistance exercise types (28).

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 workout for a minimum of 12 sessions. Consequently, it seems that, at least for well-trained athletes who have undergone an appropriate familiarization, the use of perceived exertion scales could represent an accurate, easy, practical, and economic alternative for controlling strength fluctuation in daily workouts throughout the training process.

Results of this 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 more than 80% of the predicted %1RM. The main advantage of both proposed methodologies would be the simple prediction of 1RM by only one set of 1-3 repetitions performed with the maximal possible velocity and using a submaximal load. Furthermore, a quick interpretation of performance can be obtained, and consequently, a training program could then be easily modified according to the present day's performance level. Additionally, 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 6.3 %. 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 7.3%.

Based on the data presented in Tables 1 and 2**,** in order to improve the accuracy of both models, it could be advisable to avoid very light or maximal loads. Particularly, for the AV model it would be recommended to estimate the %1RM from heavy to moderate loads reaching between 0.91 (95% CI 0.82-1.01) and 0.56 (95% CI 0.54-0.58) $m \cdot sec^{-1}$, sets 3- 6 (Table 2). For the RPE model, a broader range of intermediate loads from 37.3 % 1RM (95% CI 36.4-38.3) to 93.0 % 1RM (95% CI 92.3-93.8) eliciting values of RPE between 1 and 9, sets 2- 9 (Table 2), would produce an accurate prediction. 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 30% to 100% 1RM) of bench press exercise. However, further research will be necessary to assess the validity and accuracy of the 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 athletes in bench press. From a practical point of view, both methods would allow coaches to have a continuous control of the athletes' strength evolutions during the training process. Although the SEE shows a more accurate value for RPE equation compared to AV equation, both models seem to be accurate enough and would provide a quick and reliable estimation of the relative load used when performing bench press with submaximal loads.

REFERENCES

1. Baechle TR, Eaerle RW, and Wathen D. Resistance Training, Chapter 18,, in: *Essential of Strength Training and Conditioning (NSCA),*. TR Baechle, RW Earle, . eds. Champaing IL: Human Kinetics., 2000. pp. 395-425.

2. Bautista IJ, Chirosa IJ, Tamayo IM, Gonzalez A, Robinson JE, Chirosa LJ, and Robertson RJ. Predicting Power Output of Upper Body using the OMNI-RES Scale. *J Hum Kinet* 44: 161-169, 2014.

3. Bland JM and Altman DG. Correlation, regression, and repeated data. *BMJ* 308: 896, 1994.

4. Braith RW, Graves JE, Leggett SH, and Pollock ML. Effect of training on the relationship between maximal and submaximal strength. *Med Sci Sports Exerc* 25: 132-138, 1993.

5. Brzycki M. Strength testing: predicting a one-rep max from repetitions to fatigue. *JOPERD* 64: 88-90, 1993.

6. Drinkwater EJ, Galna B, McKenna MJ, Hunt PH, and Pyne DB. Validation of an optical encoder during free weight resistance movements and analysis of bench press sticking point power during fatigue. *J Strength Cond Res* 21: 510-517, 2007.

7. Duncan MJ, Al-Nakeeb Y, and Scurr J. Perceived exertion is related to muscle activity during leg extension exercise. *Res Sports Med* 14: 179-189, 2006.

8. Fleck SJ. Periodized strength training: A critical review. *J Strength Cond Res* 13: 82-89, 1999.

9. Freitas de Salles B, Simao R, Miranda F, da Silva Novaes J, Lemos A, and Willardson JM. Rest Interval between Sets in Strength Training. *Sport Med* 39: 765-777, 2009.

10. Gearhart RF, Jr., Goss FL, Lagally KM, Jakicic JM, Gallagher J, Gallagher KI, and Robertson RJ. Ratings of perceived exertion in active muscle during high-intensity and low-intensity resistance exercise. *J Strength Cond Res* 16: 87-91, 2002.

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

12. Harriss DJ and Atkinson G. International Journal of Sports Medicine - ethical standards in sport and exercise science research. *Int J Sports Med* 30: 701-702, 2009.

13. Hori N, Newton RU, Andrews WA, Kawamori N, McGuigan MR, and Nosaka K. Comparison of four different methods to measure power output during the hang power clean and the weighted jump squat. *J Strength Cond Res* 21: 314-320, 2007.

14. International Olympic Committee. The International Olympic Committee Anti-Doping Rules applicable to the XXII Olympic Winter Games in Sochi, in 2014, Lausanne, Switzerland: IOC. Available at: http://www.olympic.org/Documents/Games_Sochi_2014/Anti-doping/IOC_Anti-Doping_Rules_Sochi_2014-eng.pdf. 2014.

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

16. Kraft JA, Green JM, and Gast TM. Work distribution influences session ratings of perceived exertion response during resistance exercise matched for total volume. *J Strength Cond Res* 28: 2042-2046, 2014.

17. Lagally KM, Amorose AJ, and Rock B. Selection of resistance exercise intensity using ratings of perceived exertion from the OMNI-RES. *Percept Mot Skills* 108: 573-586, 2009.

18. LeSuer DA, McCormick JH, Mayhew JL, Wasserstein RL, and Arnold DM. The accuracy of prediction equations for estimating 1-RM performance in the bench press, squat, and deadlift. *J Strength Cond Res* 11: 211-213, 1997.

19. Mayhew JL, Ball TE, Arnold MD, and Bowen J. Relative muscular endurance performance as a predictor of bench press strength in college men and woman. *J Appl Sport Sci Res,* 6: 200-206, 1992.

20. Mayhew JL, Hill SP, Thompson MD, Johnson EC, and Wheeler L. Using Absolute and Relative Muscle Endurance to Estimate Maximal Strength in Young Athletes. *Int J Sports Physiol Perform* 2: 305-314, 2007.

21. Naclerio F, Chapman M, and Larumbe-Zabala E. Use of the Rate of Perceived Exertion Scales in Resistance Training: A Comment on Mayo, Iglesias-Soler, and Fernandez-Del-Olmo (2014). *Percept Mot Skills* 121: 490-493, 2015.

22. Naclerio F, Colado JC, Rhea MR, Bunker D, and Triplett NT. The influence of strength and power on muscle endurance test performance. *J Strength Cond Res* 23: 1483-1488, 2009.

23. Naclerio F, Rodríguez-Romo G, Barriopedro-Moro MI, Jimenez A, Alavar B, and Triplett NT. Control of resistance training intensiy by the omni perceived exertion scale. *J Strength Cond Res* 25: 1879–1888, 2011.

24. Rencher AC and Pun FC. Inflation of R2 in Best Subset Regression. . *Technometrics* 22: 49–53, 1980.

25. Reynolds JM, Gordon TJ, and Robergs RA. Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *J Strength Cond Res* 20: 584-592, 2006.

26. Robertson RJ, Goss FL, Aaron DJ, Gairola A, Kowallis RA, Liu Y, Randall CR, Tessmer KA, Schnorr TL, Schroeder AE, and White B. One repetition maximum prediction models for children using OMNI RPE Scale. *J Strength Cond Res* 22: 196-201, 2008.

27. Robertson RJ, Goss FL, Rutkowski J, Lenz B, Dixon C, Timmer J, Frazee K, Dube J, and Andreacci J. Concurrent Validation of the OMNI Perceived Exertion Scale For Resistance Exercise. *Med Sci Sport Exerc* 35: 333-341, 2003.

28. Suminiski RR, Robertson RJ, Arslaninan S, Kang J, Utter AC, Dasilva SJ, Goss FL, and Metz KF. Perception of Effort during resistance Exercise. *J Strength Cond Res* 11: 261-265, 1997.

29. Ware JS, Clemens CT, Mayehew JL, and Johnston TJ. Muscular endurance repetitions to predict bench press and squat strength in college football players. *J Strength Cond Res* 9: 99-103, 1995.

ACKNOWLEDGEMENTS:

The authors thank Alyssa Sherry from the Clinical Research Institute of Texas Tech University HSC and Dr. Bettina Karsten from the Department of Life and Sports Science, University of Greenwich for grammar review and editing of the manuscript.

Competing interests:

All authors declare no specific funding from grant agencies to support the present study. The authors recognize no conflicts of interest.

TABLES

Table 1. Mean and 95% confidence interval of %1RM corresponding to each RPE level for male (n=242), female (n=66), and total sample (308).

	Male			Female			Total sample		
RPE	n	Mean	95% CI	n	Mean	95% CI	n	Mean	95% CI
0	233	27.1	(26.1 – 28.1)	34	28.0	(26.6 – 29.4)	267	27.2	(26.3 – 28.1)
1	170	37.4	(36.4 – 38.5)	34	36.8	(34.7 – 38.9)	204	37.3	(36.4 – 38.3)
2	160	44.9	(43.7 – 46.0)	33	45.2	(42.7 – 47.8)	193	44.9	(43.9 – 46.0)
3	162	52.4	(51.2 – 53.6)	32	51.1	(49.0 – 53.1)	194	52.2	(51.2 – 53.2)
4	142	59.1	(57.9 – 60.3)	33	60.6	(58.6 – 62.5)	175	59.4	(58.3 – 60.4)
5	122	65.6	(64.4 – 66.8)	31	66.7	(64.8 – 68.6)	153	65.8	(64.8 – 66.8)
6	150	72.9	(71.9 – 73.9)	32	74.3	(72.7 – 75.8)	182	73.1	(72.3 – 74.0)
7	170	80.5	(79.5 – 81.5)	49	81.8	(80.2 – 83.3)	219	80.8	(79.9 – 81.6)
8	138	86.3	(85.1 – 87.4)	25	88.2	(86.7 – 89.7)	163	86.6	(85.5 – 87.6)
9	147	92.5	(91.7 – 93.4)	33	95.3	(93.9 – 96.7)	180	93.0	(92.3 – 93.8)
10	238	99.6	(99.4 – 99.9)	54	100	(100 – 100)	292	99.7	(99.5 – 99.9)

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

Table 2. Mean and 95% confidence interval of AV ($m \cdot s^1$) corresponding to each RPE level for male (n=242), female (n=66), and total sample (308).

	Male			Female			Total sample		
RPE	n	Mean	95% CI	n	Mean	95% CI	n	Mean	95% CI
0	233	1.25	(1.21 – 1.29)	34	1.24	(1.16 – 1.31)	267	1.25	(1.22 – 1.29)
1	170	1.08	(1.04 – 1.12)	34	1.11	(1.04 – 1.18)	204	1.08	(1.05 – 1.12)
2	160	0.97	(0.93 – 1.00)	33	0.89	(0.83 – 0.95)	193	0.95	(0.92 – 0.98)
3	162	0.91	(0.80 – 1.02)	32	0.91	(0.86 – 0.96)	194	0.91	(0.82 – 1.01)
4	142	0.75	(0.72 – 0.78)	33	0.76	(0.71 – 0.81)	175	0.75	(0.72 – 0.77)
5	122	0.66	(0.63 – 0.69)	31	0.67	(0.62 – 0.71)	153	0.66	(0.63 – 0.68)
6	150	0.56	(0.54 – 0.58)	32	0.56	(0.52 – 0.59)	182	0.56	(0.54 – 0.58)
7	170	0.47	(0.42 – 0.52)	49	0.46	(0.43 – 0.49)	219	0.47	(0.43 – 0.51)
8	138	0.36	(0.33 – 0.38)	25	0.35	(0.32 – 0.38)	163	0.35	(0.34 – 0.37)
9	146	0.28	(0.26 – 0.30)	33	0.23	(0.20 – 0.27)	179	0.27	(0.25 – 0.29)
10	235	0.23	(0.21 – 0.26)	54	0.25	(0.16 – 0.34)	289	0.24	(0.21 – 0.27)

Table 3. Fit of regression models to predict relative load (%1RM) (n=308).

	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	103.64	<0.001	-57.20	<0.001			1.13	0.043	<0.001	0.84			10.00
Fixed effects	107.75	<0.001	-62.97	<0.001					<0.001	0.84	0.24	0.92	7.22
Random effects	105.90	<0.001	-60.61	<0.001			1.06	0.130	<0.001	0.84	0.24	0.92	7.22
RPE													
Pooled OLS	29.55	<0.001			7.12	<0.001			<0.001	0.93			6.41
Fixed effects	29.03	<0.001			7.26	<0.001			<0.001	0.93	0.35	0.96	5.07
Random effects	29.11	<0.001			7.22	<0.001	1.10	0.042	<0.001	0.93	0.37	0.96	5.07

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.