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Research article

The validity of submaximal ratings of perceived exertion to predict one repetition maximum

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Abstract
The One Repetition Maximum (1-RM) test is commonly used to assess strength. However, direct assessments of 1-RM are time consuming and unsafe for novice lifters. Whilst various equations exist to predict 1-RM, there is limited research on the validity of these equations. The purpose of this study was to assess the validity of using sub-maximal ratings of perceived exertion (RPE) to predict 1-RM in young adults, using the Borg 6-20 RPE Scale. Twenty healthy participants (ten male (Mean ± SD, 20.8 ± 0.6 y, 75.7 ± 9.3 kg, 1.8 ± 0.07 m) and ten female (20.3 ± 0.7 y, 68.4 ± 10.0 kg, 1.68 ± 0.03 m)) completed two trials involving resistance exercises for both the upper and lower body. In the first trial the 1-RM for the bilateral biceps curl (BC) and the bilateral knee extension (KE) were determined for each participant. In the second trial, participants performed blinded repetitions which were equivalent to 20, 40 and 60 % of 1-RM for both exercises. The RPE was recorded immediately after two repetitions had been completed at each intensity. The order of intensity of the repetitions was randomly assigned with participants wearing blindfolds to exclude the possibility of pre-determined judgments about load and RPE. Individual RPE recorded at each intensity was subjected to linear regression analysis and the line of best fit was extrapolated to RPE 20 to predict 1-RM in both exercises. There was no significant difference ($p > 0.05$) between the 1-RM predicted from RPE 20 and measured 1-RM for both exercises for the men and women. Measured and predicted values for men were 46.0 ± 4.6 and 45.2 ± 6.1 kg for biceps curl, and 46.3 ± 3.8 and 43.0 ± 7.1 kg for knee extension, respectively. Measured and predicted values for women were 18.6 ± 5.7 and 19.3 ± 5.6 kg for biceps curl, and 25.5 ± 9.6 and 27.2 ± 12.6 kg for knee extension, respectively. Pearson product-moment correlation coefficients between actual and predicted 1-RM for the BC and KE were 0.97 and 0.92, respectively. These results provide evidence that submaximal ratings of perceived exertion can be used to provide reasonably accurate estimates of 1-RM in young and active men and women.

Key words: Effort perception, resistance training.

Introduction

The One-Repetition Maximum test (1-RM) is regarded as a popular test for assessing muscular strength (Mayhew et al., 1995; Niewiadomski et al., 2008; Pereira and Gomes, 2003), and the value is defined as the capacity of a defined muscle or muscle group to exert force against a resistance in a single maximum effort (Horvat et al., 2003). Percentages of an individual's 1-RM are often used by instructors, coaches and physicians to calculate and prescribe intensity for resistance training (LeSuer et al., 1997; Pereira & Gomes, 2003).

Despite its universal application, the safety of a 1-RM protocol has been questioned as individuals new to maximal load-bearing activity may incur high muscular, bone and ligament stress with the risk of serious muscular injury (Braith et al., 1993). The direct assessment of a 1-RM has also been referred to as time consuming and impractical for large groups (Brzycki, 1993; Nascimento et al., 2007). Such limitations have led to the development of prediction models which employ sub-maximal loads in order to minimise the limitations and risks of maximal strength assessment. Dohoney et al., (2002) found no exercise limitation or muscle soreness following indirect 1-RM prediction using 4-6 RM and 7-10 RM strength assessments. Additionally, Chapman et al., (1998) identified that the sub-maximal 1-RM prediction of 98 participants could be completed within 2.5 hours, compared to the 18 man-hours required for direct determination of 1-RM.

The majority of 1-RM prediction models are derived from regression equations which are based upon a strong association between maximal strength and repetitions to fatigue. Other prediction techniques include the use of anthropometric characteristics (Materko et al., 2007). LeSuer et al., (1997) examined the predictive accuracy of seven equations in estimating 1-RM performance in the bench press, squat and deadlift. They reported that only the equations of Mayhew et al. (1992) and Wathan (1994) successfully predicted the 1-RM for the bench press and only the equation of Wathan (1994) predicted the 1-RM for the squat exercise. Despite high correlations between actual 1-RM and predicted 1-RM during the deadlift, all equations significantly underestimated 1-RM values by an average of 22.2 - 33.7 lbs (9-14%).

More recent prediction equations appear to use a 'repetition-maximum' principle. In this regard, a weight that can be lifted maximally to fatigue after 6 – 10 repetitions has been used to calculate 1-RM, Dohoney et al. (2002) reported that 4-6 RM had a higher predictive accuracy compared to a more commonly used 7-10 RM testing range. In a review of the safety considerations of 1-RM determination and prediction, Niewiadomski et al., (2008) suggested that a safe 1-RM determination should not require repetitions to failure (i.e. 7-10RM). They reported that when both direct and indirect assessment requires participants to perform repetitions to muscular failure, both muscular and cardiovascular health risks will increase (Niewiadomski et al., 2008). Whilst this provides a case for the use of prediction models based exclusively on anthropometric techniques, this may be at the expense of the accuracy of the technique. Materko et al. (2007)

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observed that anthropometric measures explained 84% and 56% of male and female variance in measured 1-RM, with standard errors of 12% and 20%, respectively.

When used in accordance with the CR-10 RPE scale (Borg, 1998), the RPE has been shown to be a valid and reliable estimate of high- and low-intensity exercise (Gearhart et al., 2002), high-volume weight training (Pierce et al., 1993), for describing differences in neuromuscular activation (Pincivero et al., 2002) and the intensity of contraction between men and women (Pincivero et al., 2001; 2004). The majority of research which has utilised the RPE during studies involving resistance exercise has assessed the validity of RPE for quantifying resistance exercise intensity.

Although the principle of using sub-maximal ratings of perceived exertion to predict maximal functional capacity has been affirmed (Davies et al., 2008; Eston et al., 2005; 2006; 2008; Faulkner and Eston, 2007; Faulkner et al., 2007; Lambrick et al., 2009) we are not aware of any such research on the use of the Borg 6-20 Scale (Borg, 1998) or the Category-Ratio (CR-10) Scale for predicting 1-RM. Considering that the degree of muscular activation is highly correlated with the perception of effort (Cafarelli, 1982), and given the health and safety advantages of using submaximal repetitions to predict 1-RM, it is logical to explore the utility of the ratings of perceived exertion as a holistic assessment tool for predicting muscular strength. Therefore, the purpose of this study was to assess the efficacy of predicting 1-RM using the ratings of perceived exertion (RPE) from three sub-maximal loads.

Methods

Participants and procedures

Twenty undergraduate students (ten male (Mean ± SD, 20.8 ± 0.6 y, 75.7 ± 9.3 kg, 1.8 ± 0.07 m) and ten female (20.3 ± 0.7 y, 68.4 ± 10.0 kg, 1.68 ± 0.03 m)) (Mean ± SD, 20.5 ± 0.7 y, 72.05 ± 9.7 kg, 1.75 ± 0.05 m) volunteered for the study. Research was conducted in agreement with guidelines and policies of the ethics committee of the School of Sport and Health Sciences at the University of Exeter. The investigation consisted of two experimental sessions separated by 48 hours rest.

Orientation trial

The main purpose of the orientation trial was to establish each individual participant's 1-RM on two separate bilateral exercises; the biceps curl (BC) and knee extension (KE). Each participant received coaching on how to use correct, safe and experimentally acceptable weight lifting techniques required for study. The 1-RM tests for both lifts were performed according to guidelines established by the National Strength and Conditioning Association (NSCA; Baechle et al., 2008). In order to provide the participant with an understanding of his/her perceptual range, both low and high experiential anchors were applied. Participants were introduced to and given standardized instruction for the Borg 6 – 20 RPE scale (Borg, 1998). A low anchor was applied when the participant was sitting down in a relaxed state before any physical activity had commenced. The participant was asked to "think about the feelings in your quadriceps and try to associate them with no exertion (a rating of 6) on the Borg 6-20 scale". A high perceptual anchor was applied immediately after the participant had achieved a 1-RM. At this time, each participant was asked to "associate the feelings in the active muscles with maximal exertion (a rating of 20) on the Borg 6-20 scale".

Experimental trial

The experimental trial occurred 48 hours after the orientation trial and required participants to perform the previous exercises at sub-maximal intensities. The order of exercises was counterbalanced with one half of the group performing the knee extension exercise before the biceps curl exercise, and vice versa. Participants performed three sets of two repetitions on each exercise, with each set performed at an unknown pre-determined intensity (20, 40 or 60 percent). The order that the three intensities were presented to the participant was randomly chosen by the investigator and not made apparent to the participant. A blindfold was worn by each participant whilst lifting, to ensure they were blinded to the load, and therefore unable to make a pre-determined judgement on perceived exertion for that set.

The RPE was recorded following each set at the three prescribed intensities. During the concentric phase of the final repetition of each set, participants were reminded to think about feelings of exertion in the active muscle group. Immediately after the participant was relieved of the weight, the blindfold was removed allowing them to see and verbally report the rating of perceived exertion from the Borg 6 - 20 Scale. The participants were again blindfolded and a different %1-RM intensity was randomly selected by the investigator. The trials continued until three sets were completed, and RPE values had been recorded for each exercise.

Testing procedures

Biceps Curl. The participant performed this exercise standing with their back against the wall forming six points of contact. This included the right and left heels, lower back, both shoulder blades and the back of the head. It was made clear to the participant that these points of contact must remain throughout the lift in order to isolate the biceps throughout the movement. The exercise utilised a supine grip with both arms equidistant from the centre of the barbell bar (YORK, Philadelphia, USA), and was performed in the sagittal plane. The movement began with both arms at 180º from the elbow joint with the barbell at its closest position to the floor. The concentric phase lasted two seconds, culminating with the arms reaching full flexion. The eccentric phase then began when the barbell was lowered back towards full extension (180º) to complete a full repetition (Figure 1).

Knee Extension. Knee extension was performed using a seated, fixed leg extension machine (Life Fitness, Ely, Cambridgeshire, UK). The seated position was adjusted for each participant to ensure the knee joint was aligned to the machine's pivot point, thus allowing a standardised starting position. The predetermined weight was selected from the weight stack, and applied to bar weight at the distal and frontal aspect of both tibia. The

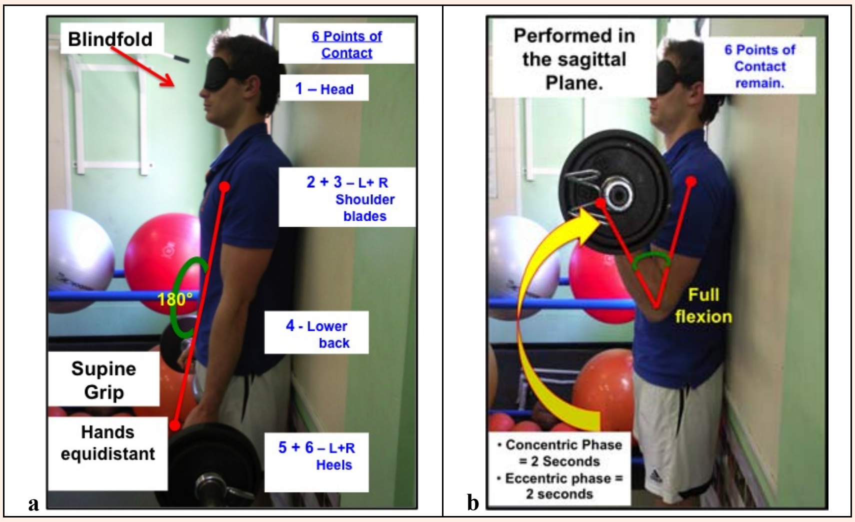

Figure 1. **Biceps curl procedure: a) elbow extension, b) elbow flexion.**

concentric part of the movement began when the tibia moved from a standardized starting position of 90º at the knee, towards full extension. Once the legs achieved 180º and were parallel to the floor, full extension was verified and the concentric phase completed. The eccentric phase was initiated when the participant's tibia moved back towards the ground (flexion) and was verified when the tibia returned to its starting position of 90º to the knee, marking a complete repetition (Figure 2).

Data analysis

Statistical significance in all tests was accepted as P = 0.05. Data were analysed using SPSS 15.0 for windows (SPSS Inc, Chicago, IL, USA). Regression analysis and graphical representation were created using Microsoft Excel (Microsoft 2007, Seattle, WA, USA). Gender differences between absolute and relative 1-RM loads were determined via paired samples t-tests. The 1-RM predictions were calculated by entering individual participant RPE values and load (kg) at each intensity into a linear regression equation and extrapolating to a theoretical 1-RM at RPE 20 (Figure 3).

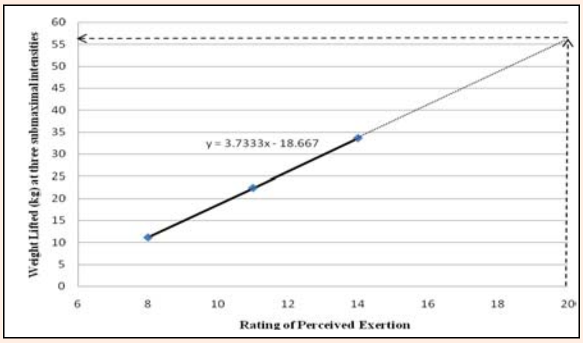

Figure 3. **Extrapolation of sub-maximal RPE and weight lifted to RPE 20 using linear regression. In the above equation, when x is RPE 20 (theoretical maximal RPE), the predicted 1-RM = 56 kg.**

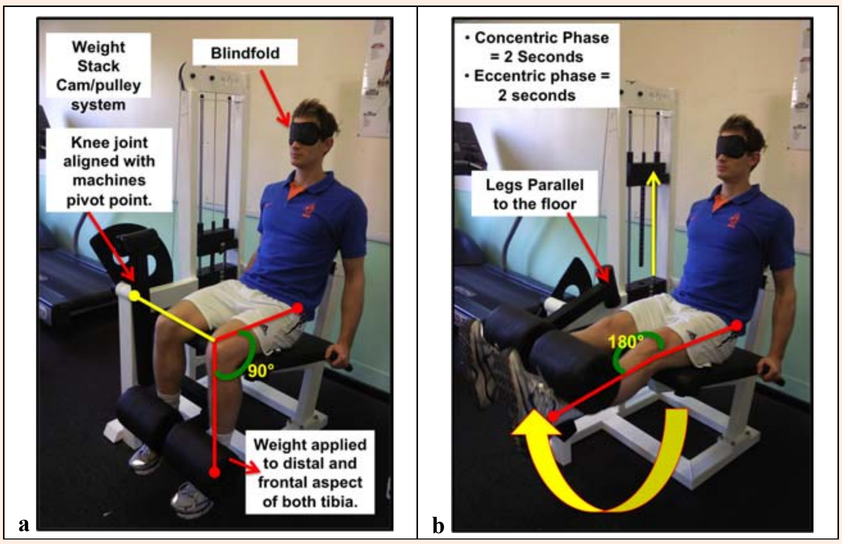

Figure 2. **Knee extension procedure: a) Knee flexion, b) knee extension.**

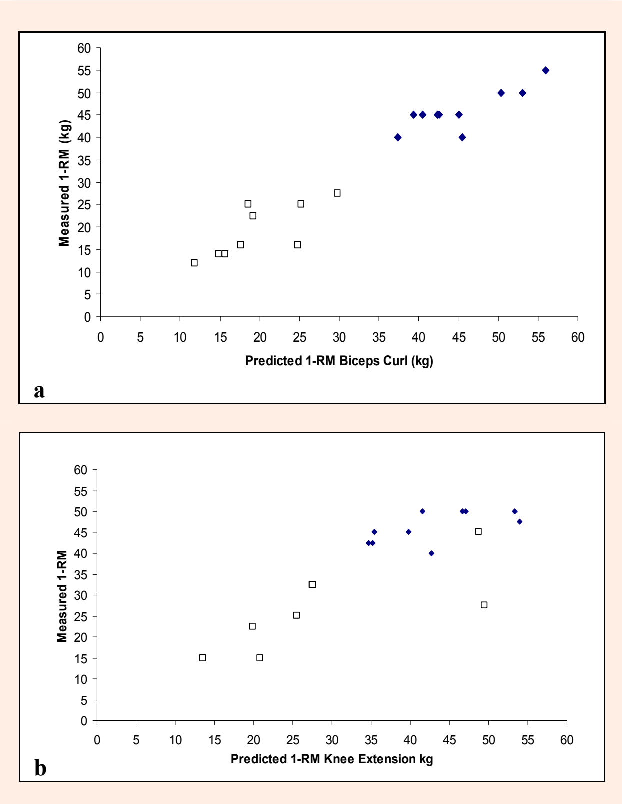

Figure 4. Predicted 1-RM versus measured 1-RM by gender (♦ male, □ female) for (a) biceps curl and (b) knee extension. The predicted values are derived from the individual relationship of the RPE with the three %1-RM values when the values are extrapolated to RPE 20. Some data points overlap.

1-RM = (b x RPE 20) + a

In the regression equation above, y (1-RM) is calculated by substituting x for 20

y = (3.73 x 20) – 18.667 = 56 kg

The *predicted* and *measured* 1-RM values for the biceps curl and the knee extension were compared for significant differences using paired samples t-tests. Linear regression analysis was used to examine relationships and explained variance between predicted and actual 1-RM for both exercises. In this investigation, the SEE% is the percentage of the actual mean 1-RM within which the predicted values are expected to fall. The percentage of the standard error of estimate (SEE) was calculated using the following equation for both the predicted biceps regression model and the predicted knee extension model:

SEE% = SEE/mean 1-RM x 100

Main effects for gender and interaction effects between predicted and measured 1-RM values for both exercises were analysed via a two-factor repeated-measures analysis of variance (ANOVA), as was predictive accuracy between participants and muscle groups. Mean predictive accuracy was expressed as the percentage of the measured 1-RM that could be predicted from measured RPE data for both muscle group and between genders:

[(Predicted 1-RM divided by actual 1-RM) multiplied by 100]

Results

Mean group data revealed no significant difference between the measured 1-RM (35.9 ± 12.8 kg) and predicted 1-RM (34.3 ± 12.4 kg) for the knee extension, $t_{(19)} = -1.40$, $p > 0.05$. Similar analysis of the biceps curl also revealed no significant differences between measured 1-RM (32.3 ± 15.0 kg) and predicted 1-RM (32.3 ± 14.4 kg) values, $t_{(19)} = -0.50$, $p > 0.05$.

Figure 4 displays positive linear relationships between the measured 1-RM and the predicted 1-RM (extrapolated from the RPE scores at the three sub-maximal intensities). Significant correlations were observed between measured and predicted values in both upper and lower body exercises for women, and for the upper body exercise in men ($p < 0.05$). The correlation for the predicted and measured 1-RM knee extension value for the males was just outside statistical significance ($p = 0.052$). The mean differences and correlation coefficients between predicted and measured values for men and women are shown in Table 1.

Predictive accuracy was expressed as the predicted percentage of measured 1-RM. There was no difference in predictive accuracy for the upper (102 ± 16%) and lower body (95 ± 14%) muscle groups ($F_{(1,18)} = 1.98$, $p > 0.05$) and no effect of gender on predictive accuracy ($F_{(1,18)} = 1.83$, $p > 0.05$, 95 ± 10% and 101 ± 19% in males and females, respectively). There was also no significant interaction of gender and muscle group on predictive accuracy ($F_{(1,18)} = 0.13$, $p > 0.05$, Figure 5).

All of the participants were able to perceive differences in the loads lifted for the knee extension, relating heavier loads with higher RPE scores. Similarly, for the biceps curl, 19 out of the 20 participants were able to perceptually differentiate between 20, 40 and 60 percent of their 1-RM loads. A two-factor (intensity x muscle group) repeated-measures ANOVA revealed significant main effects between the RPE at each of the three intensities for both the biceps curl ($F_{(2,36)}=173.6$, $p < 0.001$) and

Table 1. Paired differences and correlations between measured and predicted 1-RM.

Variable	Mean Diff kg (±SD)	Std. Error Mean	Correlation (*r*)
Biceps Curl			
Male	-3.21 (5.6)	1.78	.628
Female	.72 (3.9)	1.24	.761*
Group	-.04 (3.7)	.82	.969*
Knee Extension			
Male	-.80 (3.4)	1.09	.831*
Female	.08 (3.9)	1.24	.924*
Group	-1.57 (5.0)	1.12	.922*

*Statistically significant (p < 0.05).

the knee extension $F_{(2,36)} = 232.9$, $p < 0.001$ (Figure 6).

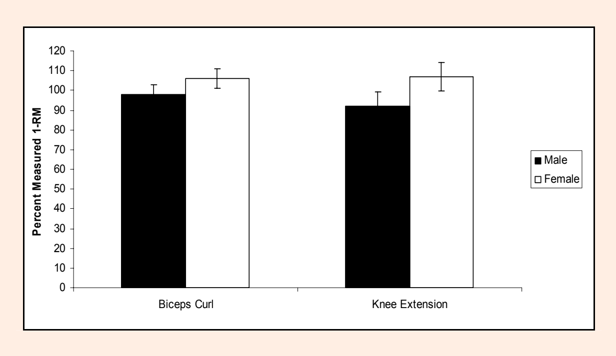

Figure 5. Average predicted percentage 1-RM (± SEM) for biceps curl and knee extension in males and females.

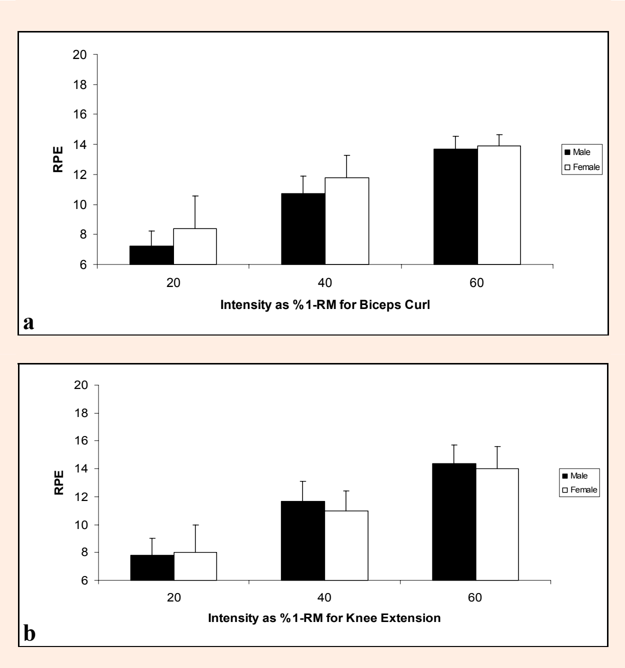

Figure 6. Comparisons between perceived exertion by gender at different intensities during the biceps curl (a) and knee extension (b). Values are mean ± SD. There was a significant difference in RPE between each intensity for both biceps curl and knee extension (p < 0.001).

Discussion

The results of this study provide encouraging support for the efficacy of using sub-maximal RPE values to predict the 1-RM in both upper and lower body muscle groups. No significant difference was found between measured 1-RM and predicted 1-RM values derived from regression equations for both the knee extension and the biceps curl. It is notable that even though the participants were blinded to the load lifted and the order by which the loads would be lifted, on 39 of the 40 occasions participants accurately distinguished between sub-maximal loads. The results concur with previous investigations, which observed statistically significant differences among mean RPE values assessed at 30% and 75% of 1-RM (Egan, 2003) using the Borg CR-10 Scale (Borg, 1998), and repetition number (4, 8, 12 and 6, 8, 10 reps in adults and children, respectively, Robertson et al., 2003; 2004). The finding of no significant difference in perceived exertion between gender at different intensities, also concurs with most previous studies (Pincivero et al., 2001; 2003, 2004; Robertson et al., 2003; 2004). However, O'Connor et al., (2002) observed that young women reported a lower perceived exertion than young males during fatiguing elbow flexion contractions.

The strong linear relationship between perceptions of effort and degree of muscular activation (intensity) has been explained on the basis of 'feel forward' hypothesis (Cafarelli, 1982). This states that during a resistance movement, corollary discharges from the motor cortex are concurrently sent to both the recipient muscle and the somatosensory cortex. The higher load results in greater tension development and increased motor unit recruitment and firing frequency (Gearhart et al., 2001). In the present study, muscle activation and therefore stimuli strength was varied with intensity. This was achieved by altering the sub-maximal loads to relative percentages (set at 20, 40 and 60%) of individual 1-RM. Stevens' psychophysical power law states that perceived exertion sensation increases linearly with the power of increasing stimuli strength (Stevens, 1957).

To our knowledge, this is the first study to examine the validity of sub-maximal perceived exertion ratings from the Borg 6-20 scale for predicting 1-RM for upper and lower body exercise. Although previous research has observed a higher predictive accuracy in 4 - 6 RM models in comparison to 7 – 10 RM prediction models (Dohoney et al., 2002), the correlations from the 4 -6 RM biceps curl (r = 0.89) and knee extension (r = 0.82) from the latter study, are no better than the results from the present study. Furthermore, in the current study only a few minutes were required by each participant to familiarise with the task of performing two sub-maximal repetitions at each of the three intensities.

Perceived exertion is contingent on the degree of muscular activation (Cafarelli, 1982), which varies according to the length of the muscle for a given load during both eccentric and concentric movements. Perceived exertion ratings are therefore dependent on the joint position throughout the range of movement. Controlling for the velocity of the muscle contraction may increase reliability in perceptions of effort across participants. In the present study, RPE was reported following two complete repetitions at each intensity, although the speed of extension and flexion of the joints was not controlled.

With the exception of the present study, there are no published studies on the efficacy of using the Borg 6-20 RPE scale for predicting maximal strength. This study observed no significant differences between measured and predicted 1-RM values for both the biceps curl and knee extension exercises. Our findings suggest that perceived exertion ratings from the Borg 6-20 Scale may be used to provide reasonably accurate estimates of 1-RM in healthy young men and women, providing a potentially accurate, safe and time-efficient determination of 1-RM. The method provides proof of principle that sub-maximal exercise intensities in the range of 20 – 60% of the 1-RM can be used estimate the 1-RM for upper and lower body exercise. It remains to be determined if the use of alternative %1-RM combinations (smaller increments in resistance) or whether practice in repeated submaximal perceptual estimation sessions with sufficient intermittent recovery periods, would lead to greater accuracy in the prediction of 1-RM, although we believe it would. Further research to test these assumptions and assess the efficacy of using perceived exertion to predict the 1-RM in other populations is recommended. Control of the velocity of muscular contraction across flexion and extension of the joints may also enhance the reliability of perceived exertion.

Conclusion

Direct 1-RM assessment is a common method of measuring maximal strength. However, it is regarded as time consuming and unsafe for novice lifters. The validity of sub-maximal perceived exertion ratings from the Borg 6-20 scale for predicting 1-RM was examined. In both upper and lower body exercises, no significant differences were observed between 1-RM scores predicted from sub-maximal RPE and 1-RM scores measured directly for men and women. Using the Borg 6-20 scale, sub-maximal ratings of perceived exertion can be used to provide reasonably accurate estimates of 1-RM for the biceps curl and leg extension in young men and women. The major advantage of this finding exists in its practical application, offering an accurate, safe and time efficient method for predicting maximal strength.

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Key points

- The direct measurement of 1-RM is time consuming and impractical for large groups. This has led to the development of prediction models which employ sub-maximal loads in order to minimise the limitations and risks of maximal strength assessment.
- The principle of using the ratings of perceived exertion from sub-maximal work rates to predict maximal work rate has been established.
- With the exception of the present study, there are no published studies on the efficacy of using the Borg 6-20 RPE scale for predicting maximal strength.
- Perceived exertion ratings from the Borg 6-20 Scale may be used to provide reasonably accurate estimates of 1-RM.
- Sub-maximal exercise intensities in the range of 20 – 60% of the 1-RM can be used estimate the 1-Repetition Maximum for upper and lower body exercise.

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