Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000001049

Novel Resistance Training-Specific RPE Scale Measuring Repetitions in Reserve

Running Head: RPE Measuring Repetitions in Reserve

R: JSCR-08-5683

Michael C. Zourdos, Ph.D.[1], Alex Klemp, M.S.[1], Chad Dolan, B.S.[1]

Justin M. Quiles, B.S.[1], Kyle A. Schau, M.S.[1], Edward Jo, Ph.D.[2], Eric Helms, M.S.[3],

Ben Esgro, M.S.[4], Scott Duncan, Ph.D.[5], Sonia Garcia Merino, Ph.D.[6],

Rocky Blanco, M.S.[1]

[1]Department of Exercise Science and Health Promotion
Muscle Physiology Laboratory
Florida Atlantic University, Boca Raton, FL.

[2]Department of Kinesiology and Health Promotion
California State Polytechnic University, Pomona, Pomona, CA

[3]Sports Performance Research Institute New Zealand (SPRINZ)
Auckland University of Technology, Auckland, New Zealand

[4]Department of Nutrition and Dietetics
Marywood University, Scranton, PA.

[5]Human Potential Centre, Auckland University of Technology,
Auckland, New Zealand

[6]Department of Motricity, Human Performance and Sport Management
European University of Madrid
Madrid, Spain

<u>*Corresponding Author*</u>
Michael C. Zourdos, Ph.D., CSCS
Assistant Professor
Department of Exercise Science and Health Promotion
Florida Atlantic University
Office: Field House 11A, Room 126A
Phone: 561-297-1317, Fax: 561-297-2839
Email: mzourdos@fau.edu

Abstract: The primary aim of this study was to compare rating of perceived exertion (RPE) values measuring repetitions in reserve (RIR) at particular intensities of 1RM in experienced (ES) and novice squatters (NS). Further, this investigation compared average velocity between ES and NS at the same intensities. Twenty-nine individuals (24.0±3.4yrs.) performed a one-repetition maximum (1RM) squat followed by a single repetition with loads corresponding to 60, 75, and 90% of 1RM and an 8-repetition set at 70% 1RM. Average velocity was recorded at 60, 75, and 90% 1RM and on the first and last repetitions of the 8-repetition set. Subjects reported an RPE value that corresponded to an RIR value (RPE-10 = 0-RIR, RPE-9 = 1-RIR, and so forth). Subjects were assigned to one of two groups: 1) ES (n=15, training age: 5.2±3.5yrs.), 2) NS (n=14, training age: 0.4±0.6yrs.). The mean of the average velocities for ES were slower (P<0.05) than NS at 100% and 90% 1RM. However, there were no differences (P>0.05) between groups at 60%, 75%, or for the 1st and 8th repetitions at 70% 1RM. Additionally, ES recorded greater RPE at 1RM than NS (P=0.023). In ES there was a strong inverse relationship between average velocity and RPE at all percentages (r= -0.88, P<0.001), and a strong inverse correlation in NS between Abstract: The primary aim of this study was to compare rating of perceived exertion (RPE) values measuring repetitions in reserve (RIR) at particular intensities of 1RM in experienced (ES) and novice squatters (NS). Further, this investigation compared average velocity between ES and NS at the same intensities. Twenty-nine individuals (24.0±3.4yrs.) performed a one-repetition maximum (1RM) squat followed by a single repetition with loads corresponding to 60, 75, and 90% of 1RM and an 8-repetition set at 70% 1RM. Average velocity was recorded at 60, 75, and 90% 1RM and on the first and last repetitions of the 8-repetition set. Subjects reported an RPE value that corresponded to an RIR value (RPE-10 = 0-RIR, RPE-9 = 1-RIR, and so forth). Subjects were assigned to one of two groups: 1) ES (n=15, training age: 5.2±3.5yrs.), 2) NS (n=14, training age: 0.4±0.6yrs.). The mean of the average velocities for ES were slower (P<0.05) than NS at 100% and 90% 1RM. However, there were no differences (P>0.05) between groups at 60%, 75%, or for the 1st and 8th repetitions at 70% 1RM. Additionally, ES recorded greater RPE at 1RM than NS (P=0.023). In ES there was a strong inverse relationship between average velocity and RPE at all percentages (r= -0.88, P<0.001), and a strong inverse correlation in NS between

Keywords: Autoregulation; efficiency; Strength Exercise, Effort; Percentage of 1RM

INTRODUCTION

The most widely employed method for determining training loads within a periodized program (7, 36) is by utilizing a load commensurate with a specific percentage of the athletes' pre-determined one-repetition maximum (1RM) (8). However, a 1RM value may be limited due to atypical lifting performance or test administrator errors. Thus, flaws of a 1RM test could conceivably lead to inadequate training prescriptions, which in turn would preclude appropriate neuromuscular stimuli for optimal training adaptations. Alternative to percentage-based training, a repetition maximum (RM) training zone (i.e. 3-5, 6-8, or 9-11 repetitions) has also been a common method for prescribing training load (8). However, this too may be limited in efficacy as the training zone RM load is dependent upon 1RM or maximum strength assessments and promotes training to failure. Moreover, failure training may not always be the optimum approach for strength development (35). Objective measures should be incorporated to ensure that the physiological strain on skeletal muscle corroborates with the mesocycle foci (i.e. volume or intensity), and to account for day-to-day fluctuations in training performance. Therefore, a resistance training protocol allowing for daily and weekly load prescription (17) based upon athlete-feedback and recent performance, may be most conducive to continued adaptation.

This theory of altering training variables in response to athlete-feedback can be referred to as autoregulation (AR). Specifically, AR in resistance training has been defined as a sub-type of periodization designed to match increases in training load and volume with individual rates of adaptation (17). This strategy may be an efficient method for training progression since previous data has reported that the rate of adaptation (31) and recovery (6) from training is individualized. Further, when integrating AR into a periodized model, an objective and practical system to gauge appropriate training loads must still be utilized. It is possible for an individual to adjust training load intra-session based on objective data from force plates, accelerometers, and video analysis. However, in the absence of laboratory equipment, perhaps the most practical way to monitor daily performance and make adjustments to training load is by a rating of perceived exertion

(RPE) scale. Traditionally, RPE has been utilized to gauge exertion and regulate intensity in aerobic exercise. More recently however, RPE-based methods have been used for intra-training feedback on perceived exertion during explosive resistance training (26), allowing lifters to appropriately manage intensity to maximize power output; and to measure total session fatigue of a resistance training bout (4, 28, 30). The two RPE scales under investigation are a 15-point scale (range: 6-20) and a 10-point scale (range: 1-10) with the lower values denoting less effort and higher levels signifying greater effort. Predictably, higher RPE values have been frequently associated with greater intensity of exercise (11, 15, 23), blood lactate accumulation (16, 21, 27), and greater electromyographic activity (16, 22, 24).

Practicality issues exist when utilizing RPE during resistance training. It has been reported that the precision of an athlete's ability to assess RPE is enhanced with experience (30), suggesting that RPE may not be accurately assigned by novice lifters. Since utilization of RPE requires a learning curve, a more practical and objective approach to gauge RPE warrants investigation. RPE scales were originally developed for endurance training due to its low-force, submaximal nature, and in which exertion is more likely to occur because of the length of exercise. However, because of the acute nature of resistance training, exertion may not be an appropriate surrogate for intensity. For resistance training perhaps examining the number of 'repetitions in reserve' (RIR) after the conclusion of each set is a more appropriate surrogate as a perceptual intensity assessment than the traditional mode of RPE (i.e. an RPE value corresponding to a certain amount of repetitions, which could still be performed-RIR). Indeed, an RPE scale of this type has been utilized in strength sports (i.e. powerlifting), since publication of the Reactive Training Systems Manual in 2008 (32). Further, Hackett and colleagues (2012) compared a traditional RPE scale to that of one based on RIR and found that even when muscular failure was achieved, maximal RPE values were not recorded (12). Thus, it was concluded that RIR might be a more appropriate measure of resistance training intensity than traditional RPE scales; however, an RPE scale based on RIR (i.e. a combined scale) has yet to be investigated in the scientific literature. Therefore, in addition to monitoring fatigue, if RPE is examined at known percentages of 1RM, individuals will have a known commodity to assign RPE and utilize this scale as a practical and objective method of AR. Objective performance feedback via movement velocity measurements may be associated with RPE values to further validate the use of an RIR-based RPE scale. For instance, RPE and velocity should conceivably share a proportionately indirect relationship such that higher RPEs are recorded with greater effort and vice versa. To our knowledge, it remains unknown if a scale of this type can be used appropriately in both an experienced and novice population of lifters.

Therefore, the primary aim of this study was to compare RPE ratings based on RIR, whereby an RPE 10 is equal to 0 RIR, an RPE 9 is equal to 1 RIR and so on at 100%, 60%, 70%, 75%, and 90% of 1RM in experienced and novice squatters during the back squat exercise. Further, since bar velocity decreases as a lifter approaches a 1RM (10), a secondary aim was to determine if there was indeed an inverse relationship between RPE/RIR and average velocity which would indicate whether or not RPE/RIR was a valid measure of resistance training intensity. Finally, we aimed to compare average velocities at given intensities between experienced and novice populations in the back squat. It was hypothesized that RIR could be used to effectively quantify intensity, in that there would be an inverse relationship between both percentage of 1RM, RPE/RIR and velocity; thus as load was increased and velocity diminished

RPE values would increase noting less RIR. Further, it was hypothesized that experienced lifters would record slower velocities than novice lifters at a higher load due to superior skill and efficiency (i.e. motor unit recruitment) during the squat exercise.

METHODS

Experimental Approach to the Problem

This study was designed to examine RIR as reported by a 1-10 RPE scale (Figure 1) and corresponding velocities in the back squat exercise. All subjects performed the same protocol but were assigned to one of two groups, experienced squatters (ES, n = 15) or novice squatters (NS, n= 14). All subjects reported to the laboratory for one day. Upon arrival to the laboratory subjects underwent anthropometric assessments and then completed a 5-minute standardized dynamic warm-up consisting of body weight movements to prepare for exercise. Following the dynamic warm-up subjects performed back squat 1RM testing in accordance with USA Powerlifting (USAPL) specifications (33). Following the 1RM test, subjects completed one set of one repetition at 60, 75 and 90% of the established 1RM followed by one set of 8 repetitions at 70%. A 5-minute rest period was administered between all sets. During 1RM testing and all single repetition sets average velocity (m•s^{-1}) was recorded along with RIR via the RPE scale. Additionally, average velocity was recorded on the first and last repetitions of the 70% set of 8 repetitions and subjects reported RPE at the end of this set. The set of 8 repetitions with 70% was included since previous data has reported greater precision of athletes to report RPE during resistance training protocols of repeated bouts and higher volumes (30).

INSERT FIGURE 1 ABOUT HERE

Subjects

Twenty-nine college-aged subjects (males, n = 23, females, n = 6, body mass = 86.2 ± 19.1 kg, body fat = 16.2 ± 5.2%) participated in the current study. Subjects were assigned to the ES or NS group based on previous training experience with the squat exercise. Those who indicated a training experience of two years or greater and a minimum squat frequency of once per week, were classified as ES (n=15, 12 males and 3 females), while subjects with less than 1 year of training experience and had been performing the squat at least once every two weeks were classified as NS (n=14, 11 males and 3 females). In addition to the above criteria, male subjects in ES had to meet a minimum Wilks coefficient of 90 and females had to meet a minimum Wilks coefficient of 70 to qualify for ES. Subjects' squat experience was determined with the use of a physical activity questionnaire, which has been used in prior research to assess training experience (37). Additionally, subjects also provided written informed consent prior to participation, and the Florida Atlantic University institutional review board approved this study.

INSERT TABLE 1 ABOUT HERE

Procedures

One-Repetition Maximum (1RM). The 1RM testing protocol was administered following a dynamic warm-up and all lifts were performed in accordance to the specifications of USAPL rules and regulations (33). Therefore, subjects were instructed to perform the eccentric portion of each trial to a minimum depth in which the hip crease passes below the top of the knee when viewed from the lateral aspect. To successfully complete the concentric portion subjects returned to an erect standing position on their own volition, with no downward movement of the barbell, and upon standing waited for a 'rack' command from the investigator before placing the barbell in the racks. If the subject failed to complete the lift accordingly the trial was deemed unsuccessful. In preparation for 1RM determination subjects first performed 5 repetitions with 20% of their estimated 1RM, followed by 3 repetitions at 50% of estimated 1RM, and 2 repetitions at 75% 1RM. Next, subjects performed one repetition at 85% of estimated 1RM and then proceeded to find their 1RM with weights selected by the investigator. The investigator used athlete-feedback from the RPE scale along with average velocity of each attempt to determine the subsequent attempt. A 1RM was established in accordance with one of three situations, 1) Recording of a 10 RPE by the subject and the investigator also determining an increased load for the ensuing attempt would not be successfully completed, 2) An RPE of 9 or 9.5 being recorded followed by the subject failing on the next attempt with a load increase of ≤ 2.5kg, or 3) An RPE of < 9 being recorded and the subject failing on the next attempt with a load increase of ≤ 5kg. The primary investigator who determined if the lifts were performed appropriately and selected 1RM attempts was an experienced Certified Strength and Conditioning Specialist (CSCS) and USAPL referee.

Rating of Perceived Exertion (RPE) and Repetitions in Reserve (RIR). Immediately following the completion of 1RM attempts as well as the 60, 75, 90, and 70% sets, subjects were shown a 1-10 RPE scale (Figure 1) and were verbally asked to provide an RPE value. Prior to testing investigators verbally explained the details of the RPE scale by using the following script: "This

RPE scale will measure repetitions in reserve. For instance, a 10 RPE represents 'max effort' or no more repetitions could be performed. A 9.5 RPE means you could not do another repetition, but could add more weight. A 9 RPE means you could do one more repetition. An 8.5 RPE means you could do between 1-2 more repetitions. An 8 RPE means you could do 2 more repetitions. A 7.5 RPE means you could do between 2-3 more repetitions. A 7 RPE means you could do 3 more repetitions, a 5-6 RPE means you could do 4-6 more repetitions, a 3-4 RPE indicates that the set was of little effort, while an RPE of 1-2 indicates that the set was of little to no effort."

Average Velocity. All subjects had average velocity ($m \cdot s^{-1}$) of the barbell measured by the Tendo Weightlifting Analyzer (TENDO Sports Machines, Trencin, Slovak Republic) during all squats. The Tendo unit consists of two components, a velocity sensor and display unit. The velocity sensor was placed on the floor, the Tendo cord was attached to the barbell just inside of the 'sleeve' using a velcro strap. The Tendo was attached so that perpendicular angle between the Tendo and barbell was achieved during the squat. The display unit calculated average velocity, which was then manually recorded by the investigator. This setup was in accordance with Tendo Weightlifting Analyzer User's Guide. Tendo had a frequency of data sampling every 1cm of displacement during the concentric portion of the lift.

Wilks Coefficient. Wilks coefficient is used by the USAPL to determine relative strength (21). This coefficient is calculated by multiplying the weight lifted by a standardized bodyweight coefficient number, and has been previously validated in the scientific literature as a valid measure to assess relative strength (34). This value was calculated in the present study to determine differences in relative strength between groups.

Body Fat Percentage. Body fat was estimated by using the average sum of two measurements of skinfold thickness acquired from three sites for males (abdomen, front thigh, and chest) and females (triceps, suprailiac, and thigh); if any site was >2 mm different between measurement then a 3rd measurement was taken. The Jackson and Pollock formula was utilized to compute body fat percentage (13). The same investigator administered the skinfold measurement for each subject.

Physical Activity Questionnaire. Each subject completed a physical activity questionnaire during their initial visit to the laboratory to obtain greater background information regarding resistance training history in order to appropriately place subjects into either the ES or NS group. Subjects provided information regarding number of years of involvement in resistance training, along with a description of their current training program, and an estimate of current 1RM back squat. Subjects were required to refrain from exercise for 48 hours prior to the laboratory testing session.

Statistical Analyses

ES and NS subject characteristics were analyzed at baseline using independent-samples t-tests to determine if differences between groups existed prior to testing. Differences in average velocities between ES and NS were also examined using independent-samples t-tests for all single repetition sets. To express the potential range of RPE values that could be reported by both ES and NS based on our population sample, means and 95% confidence limits (CL) for RPE were calculated for all squat intensities. However as expected, the RPE values at 1RM were not normally distributed. This is because RPE has a natural limit of 10, and thus utilizing CL for RPE values at 1RM does not perfectly represent this data. Therefore, to express the differences in RPE values at 1RM between ES and NS the Chi Squared non-parametric null hypothesis test was also performed and to express the spread of data the median and interquartile ranges were calculated as well. Correlation coefficient *r* scores and their associated *P* values were calculated to quantify the associations among average velocity and RPE at all squat intensities for both NS and ES. Correlations were interpreted and reported as "weak" if they were less than or equal to 0.35, "moderate" if they fell between 0.36 to 0.67, "strong" if they fell between 0.68 to 0.89, and "very strong" if they were equal or greater than .90 (29). The coefficient of determination r^2 score was also calculated to express the explained variance of the correlation coefficients. Changes in average velocity at 70% 1RM between the first and last repetitions were compared between NS and ES using a factorial repeated-measures ANOVA (set by group). All statistical analyses were performed using Statistica® 12 for Windows (StatSoft; Tulsa, OK, USA) and the level of significance was set at $p \leq 0.05$.

RESULTS

Subject Characteristics

There was no significant difference ($P > 0.05$) between groups for height, body mass and body fat percentage. However, as expected, there were significantly greater ($P < 0.05$) values for ES compared to NS in absolute squat 1RM, Wilks coefficient, and training age. The specific values for all descriptive measures can be seen in Table 1.

Average Velocity

Figure 2 displays means of the average velocities for ES and NS at 100%, 90%, 75% and 60% of 1RM. At 100% 1RM, ES recorded a significantly ($P < 0.001$) slower average velocity (0.24 ± 0.04 m·s^{-1}) compared to NS (0.34 ± 0.07 m·s^{-1}). Similarly, ES performed 90% of 1RM at a significantly ($P < 0.001$) slower average velocity than NS (ES = 0.34 ± 0.07 m·s^{-1}, NS = 0.46 ± 0.09 m·s^{-1}). However, no significant ($P > 0.05$) differences existed between groups for average velocity at 75 and 60% of 1RM. Additionally, there was no group difference ($P > 0.05$) in average velocity of the first or final repetition of the eight-repetition set at 70% of 1RM. There was also no between-group difference ($P > 0.05$) in the change in average velocity between the first and final repetition of the eight-repetition set at 70% of 1RM (data not shown).

INSERT FIGURE 2 ABOUT HERE

Rating of Perceived Exertion and Repetitions in Reserve

Table 2 displays the 95% confidence intervals (CI) for RPE in ES and NS for 100% of 1RM, 90%, 75% and 60% of 1RM respectively. Table 3 displays RIR associated with the 95% CI's for RPE in ES and NS for 1RM, 90%, 75%, and 60% of 1RM respectively and cross references these values with the "Percent of the 1RM and Repetitions Allowed" guidelines from the National Strength and Conditioning Association's (NSCA) "Essentials of Strength and Conditioning" (1). Chi Squared analysis of RPE at 1RM found that ES recorded a significantly (P = 0.023) higher average RPE (9.80 ± 0.18) than NS (8.96 ± 0.43). Figure 3 displays the RPE values recorded by ES and NS at 1RM as the percentages of how many participants in each group selected each RPE. It was observed that 93.34% of ES (14 out of 15) recorded an RPE value at 1RM of ≥ 9.5, while 57.14% of NS (8 out of 14) recorded an RPE value of ≤ 9 at 1RM.

INSERT TABLE 2 ABOUT HERE

INSERT TABLE 3 ABOUT HERE

Relationship of Average Velocity with Rating of Perceived Exertion

In ES when all repetition and velocity data was pooled, average velocity at all percentages of 1RM had a strong inverse relationship with RPE (r = -0.88, P < 0.001). In NS, a strong inverse correlation between average velocity at all percentages of 1RM and RPE was observed (r = -0.77, P = 0.001). In ES, 78% (r^2 = 0.78) of this inverse correlation between movement velocity and relative load can be explained by the relationship between RPE and velocity at all percentages of 1RM, while in NS the proportion was 60% (r^2 = 0.60).

INSERT FIGURE 3 ABOUT HERE

DISCUSSION

Appropriate assignment of training loads during resistance training is paramount to attain desired adaptations. Correspondingly, this study was the first to our knowledge to evaluate the efficacy of a RIR-based RPE scale during resistance exercise for use in autoregulating training loads. An additional novelty of this investigation was that movement velocities were correlated with RPE values in both novice and experienced training populations. Both of our hypotheses were supported, in that 1) there was a strong inverse relationship between average velocity at all intensities and RPE in both ES (r = -0.88) and NS (r = -0.77) and 2) ES produced slower average velocities than NS at 100% 1RM (ES = 0.24 ± 0.04 $m \cdot s^{-1}$, NS = 0.34 ± 0.07 $m \cdot s^{-1}$) as well as at 90% of 1RM (ES = 0.34 ± 0.07 $m \cdot s^{-1}$, NS = 0.46 ± 0.09 $m \cdot s^{-1}$). Moreover, ES exhibited a higher RPE at 1RM than NS possibly signaling lower rate of force development due to diminished ability to recruit high-threshold motor units in NS (2, 18), and the inability of NS to perform a true 1RM. Finally, RIR at 75% of 1RM as reported by our subjects indicates that on average less repetitions (5-7) may be performed at this intensity than suggested by the established 'repetitions allowed' table (1), which permits for 10 repetitions at this intensity. However, at 90% our data allows for up to 4 repetitions, which is similar to traditional recommendations. In summary, using RPE to gauge RIR seems to be a practical and effective method to autoregulate intensity during resistance training sessions.

The theory of RPE has been previously examined in resistance training models (9) and has been advocated (5). However, these investigations have reported session RPE (4, 28, 30) or have not specifically measured RIR at known intensities, leaving much to be desired. Therefore, the current investigation provides novelty by using RPE based on RIR. Interestingly, ES produced slower velocities and recorded higher RPE values at greater intensities (i.e. 90% and

100% 1RM) when compared to NS. It is possible that an individual's height could be responsible for a variance in movement velocity due to differences in limb lengths; however, there was no difference in height between ES and NS in the present investigation. Therefore, these findings may be explained in 2 ways: 1) ES have greater efficiency with heavy loads due to enhanced high-threshold motor unit recruitment, 2) NS may be incapable of performing a true 1RM due to their inability to effectively train with maximal or near maximal loads. In fact, previous research has demonstrated significant neuromuscular adaptations and enhanced ability to recruit high-threshold motor units with an increased training status (2, 18). When considering the difference in mean training age between groups (i.e. ES > 5 years vs. NS < 6 months), it can be speculated that ES possessed superior motor skills while squatting and neuromuscular efficiency, possibly due to enhanced recruitment of high-threshold motor units. Further, it initially seems contradictory that NS had an average 1RM RPE of 9.0 compared to 9.8 with ES, because an RPE of 9 indicates one full repetition remaining. However, a 1RM in this study was defined by recording an RPE of 10 or recording a submaximal RPE and failing on a subsequent attempt with a load increase of ≤ 2.5kg. Indeed, 100% of the ES population recorded an RPE ≥ 9 following their 1RM lift, while 35.71% of NS specified an RPE less than 9. Additionally, only 14.29% NS were able to record an RPE of 10, while 66.67% ES recorded an RPE of 10. Furthermore, repeated efforts and high volume may enhance sensory feedback from involved skeletal muscles to improve the accuracy of perception (3, 20, 30), suggesting NS may have provided a more accurate RPE value on the 8-repetition set. Therefore, it is possible that NS recorded less accurate RPEs during the 1RM test since it was low volume (i.e. only one repetition).

Regardless of training population, percentage of 1RM is the most common and recommended method of assigning training load (8). Even though percentage of 1RM is commonly used it must be noted that for this to be viable the 1RM test itself must be valid, in other words the end result is accurate. However, previous literature has allowed a reduction in 1RM attempt load following a missed attempt (14). Consequently, lifters are likely performing in a fatigued state following a missed attempt, which calls into question attempt selection strategies of the investigators. Additionally, previous research has classified a 1RM as 2 consecutive missed attempts with as much as a 5kg increase (30). This strategy may also be invalid as a 2.5kg increase in load can be made even in the absence of fractional weight plates, thus, enhancing the precision of 1RM attempts. Also, there is no validated measure of practical athlete feedback (RPE/RIR scale) and objective measure of performance during 1RM attempts (average velocity). The experimental RPE scale examined in this study allows for practical feedback in which an individual can not only identify how many repetitions they have in reserve, but also can relate that to a specific intensity to choose the next 1RM attempt appropriately. Additionally, our method of 1RM testing, which took into account both RPE/RIR scores and average velocity to choose subsequent attempts, can be implemented in future investigations to effectively determine a subject's 1RM.

Previous literature from Baechle and Earle (1), presents a table indicating the number of repetitions allowed within a given set for a given percentage of 1RM. References such as this are quite valuable to trainees and coaches, and our data agrees with Baechle and Earle in that there is a linear relationship between load lifted and repetitions allowed. However, the RPE/RIR scores in the present study suggest some similarities and some differences in repetitions allowed compared to the traditional recommendations (1). For example, the traditional recommendations allow for 4 repetitions at 90% 1RM while the RPE/RIR scores in the present study for both ES and NS indicates that 3-4 repetitions could be performed. Additionally, traditional recommendations allow for 11 repetitions at 70%, which is similar to our data. Contrastingly, the traditional recommendations allows for 10 repetitions at 75% whereas our data indicates 5-7+ repetitions could be performed in both ES and NS. Interestingly, individual differences seem to be present between repetitions allowed at a given intensity as in the present study range there was a range of RPE scores from 4 to 7 in ES at 75% of 1RM and from 3 to 7 in NS at 75% of 1RM. Another explanation for the variance of RPE in the 75% set compared to traditional recommendations, is that RPE scores may be more accurate following higher volume sets and sets closer to failure (i.e. the 8-repetition set at 70% and the 90% and 100% 1RM single repetition sets), and thus the lower strain of the set (i.e. lower RPE) the more error involved in estimating RIR. Moreover, data also suggest that perceptual responses may be different at low vs. high intensities with the perception at lower intensities (25) focusing on fatigue and the perception at higher intensities more focused on the actual load, thus when estimating RIR it may be easier to do so at greater intensities. Additionally, RPE values ranged following the eight-repetition set at 70% in ES from 6.5 to 10 and in NS from 5 to 9. Ultimately, autoregulating training via the RPE scale may be necessary to account for individual differences in repetitions allowed.

Finally, in addition to utilizing AR to assign training load on a given day, previous research indicated merit to auto-regulating weekly load progressions (17, 37). This tactic, termed 'autoregulatory progressive resistance exercise' (APRE) by Mann et al. (17), demonstrated that when training load was adjusted weekly based upon the previous week's performance strength outcomes were significantly greater than when load was pre-assigned via %1RM without any regard for recent performance. Similarly, previous literature has shown efficacy for 'flexible' non-linear periodization (FNLP), which is another variant of autoregulation. McNamara and Stearne (2010) implemented FNLP in which subjects could choose between 20-repetition, 15-repetition, and 10-repetition training sessions based upon their perceived recovery versus a group with a fixed training order of non-linear periodization. The FNLP strategy was in essence a form of autoregulation and resulted in superior strength enhancement compared to the fixed order of non-linear periodization (19). Thus, it does seem that AR is important for weekly progression and daily load assignment. However, a current limitation in these long-term training studies is that even when AR is used as a progression model a fixed amount is still added to the training load. Thus, even though the progression is contingent upon performance, adding a fixed amount of weight does not account for daily alterations in training readiness. Autoregulation is useful to ensure the appropriate physiological strain is placed on the muscle; therefore the RIR-based RPE scale is a valuable tool to appropriately stress the muscle within a yearly macrocycle. Specifically, if a lifter is training in a volume block, the nature of the block is submaximal, thus a goal RPE of 6-8 could be established for each set to allow for repeated sets and high volume at a given load. Consequently, if an achieved RPE which is too low or high, training load can be altered accordingly and objectively. For example, an RPE of 9 or 10 could require a load reduction of 2.5 or 5kg., respectively. In this respect, an RIR-based RPE scale may be preferred for load assignment to the traditional methods of percentage of 1RM or prescribed RM zones, as RMs by nature involve failure training, and thus, offer little flexibility in training loads and exertion. Additionally, RPE can be utilized for power-focused sessions to indirectly gauge velocity, if a technological velocity calculator (i.e. Tendo unit, transducer, etc.) is not available. For example, the athlete can have a maximum RPE for a training session, which is low (i.e. ≤4), in order to ensure a high velocity is maintained; since the current study has established an inverse relationship between RIR-based RPE and average velocity. Further, the proposed model lends itself well for load alterations in integrated periodized configurations. Particularly, autoregulation can be useful within a model, which employs a daily undulating programming strategy (i.e. altering repetitions within a week), yet fits into the yearly structure of linear/block periodization. Therefore, future long-term training studies should be performed using AR as a model for both progression and daily load prescription.

In summary, the present study examined a novel RPE scale for resistance training specifically measuring RIR as well as average velocity corresponding to RPE values at known intensities. This investigation confirmed the validity of the RIR-based RPE scale as average velocity at all percentages of 1RM had a significant and strong inverse relationship with both ES (r = -0.88, P < 0.001) and NS (r = -0.77, P = 0.001). Further, this study found that ES were able to perform a 1RM at a slower velocity while recording a higher RPE than NS. Additionally, compared to traditional recommendations our data has some agreement and some dissimilar findings in reference to repetitions allowed at various percentages of 1RM. The dissimilar findings for repetitions allowed compared to traditional recommendations occurred at lower intensities and are likely due to RIR being more difficult to estimate when a greater amount of repetitions remain.

PRACTICAL APPLICATIONS

These findings demonstrate that experienced and novice lifters may not possess equal abilities to perform a true 1RM lift, and as a result it may not be appropriate to use % of 1RM as a method to assign training load in all populations. Therefore, we propose 2 suggestions from a practical stance: 1. That the RPE/RIR scale presented in the present study be used as a method to assign daily training load and aid in session-to-session load progression, and 2. That the proposed scale be implemented in 1RM tests both in future research and during individual training to increase the efficacy of testing. Thinking further, individual differences may exist in repetitions allowed at a given intensity. Therefore, if percentage of 1RM is used to assign training load and number of repetitions to be performed, perhaps using the RIR-based RPE scale during an initial testing session could detect these individual differences. For example, the suggested intensity for an 8-repetition set may be person-dependent (i.e. 65%, 70%, or 75% of 1RM). Moreover, the practical implementation of this scale is quite wide-ranging, and we recommend that future research be conducted utilizing the proposed RPE/RIR scale as both a method of daily load assignment and to provide a basis for progression session-to-session and weekly load progression. Specifically, if a training block is focused on submaximal volume (i.e. RPE 6-8 for each set) load can be continually adjusted to ensure the appropriate number of RIR, which would allow for repeated efforts at the same training load. Whereas, an intensity-focused block would have a higher goal RPE (i.e. 9-10) and load could again be adjusted accordingly based upon RIR to ensure appropriate adaptation. Additionally, RPE can be utilized to gauge velocity during power-based training sessions by setting a maximum RPE and when the maximum RPE is reached the set would be terminated, to ensure the appropriate stressor of the training session is maintained. Ultimately, this resistance training-specific RPE scale can be used within a periodized model to assign training load and ensure the appropriate stressor is applied, especially when training variables are altered frequently. Finally, since individual differences exist in repetitions allowed at a given intensity, implementation of RIR-based RPE is a practical and effective way for individual athletes and teams to undergo a similar training stimulus while reducing the risk of failure.

Acknowledgements

The authors would like to thank the subjects for giving their time and effort to this project.

Table and Figure Legend

Table 1. Group Descriptive Measures. ES= Experienced Squatter Group, NS= Novice Squatter Group, RM= repetition maximum. * = Significant ($p<0.001$) between-group difference

Table 2. 95% Confidence Intervals, Median, and Interquartile Range for Rating of Perceived Exertion (RPE) at 100%, 90%, 75%, and 60% of 1 Repetition Maximum for Experienced and Novice Experimental Groups. ES= Experienced Squatter Group, NS= Novice Squatter Group, RM= repetition maximum.

Table 3. Percent 1RM and Repetitions Allowed Relationship: Traditional vs. Proposed Relationships.
CL= Confidence Limit.

Figure 1. Experimental scale for Rating of Perceived Exertion (RPE) for resistance exercise. Values in the rating column correspond to the repetitions in reserve or perceived level of exertion indicated in the adjacent description column. Descriptions of perceived exertion are associated with the number of repetitions in reserve (RIR).

Figure 2. Mean Average Velocities at 100%, 90%, 75%, and 60% of 1 Repetition Maximum for Experienced and Novice Experimental Groups. ES= Experienced Squatter Group, NS= Novice Squatter Group, RM= repetition maximum. * = Significantly ($p<0.001$) greater than ES

Figure 3. Relative Distribution of RPE Values at 100% 1RM for Experienced (ES) and Novice (NS) squatters.

References

1. Baechle TR and R.W. E. *Essentials of Strength Training and Conditioning* Champaign, IL: Human Kinetics, 2008.

2. Behm DG. Neuromuscular implications and applications of resistance training. *The Journal of Strength & Conditioning Research* 9: 264-274, 1995.

3. Davies RC, Rowlands AV, and Eston RG. Effect of exercise-induced muscle damage on ventilatory and perceived exertion responses to moderate and severe intensity cycle exercise. *European Journal of Applied Physiology* 107: 11-19, 2009.

4. Day ML, McGuigan MR, Brice G, and Foster C. Monitoring exercise intensity during resistance training using the session RPE scale. *The Journal of Strength & Conditioning Research* 18: 353-358, 2004.

5. Ekkekakis P and Petruzzello SJ. Acute aerobic exercise and affect: current status, problems and prospects regarding dose-response. *Sports Medicine* 28: 337-374, 1999.

6. Fisher J, Steele J, Bruce-Low S, and Smith D. Evidence-based resistance training recommendations. *Sports Medicine* 15: 147-162, 2011.

7. Fleck SJ. Periodized Strength Training: A Critical Review. *The Journal of Strength & Conditioning Research* 13: 82-89, 1999.

8. Fleck SJ and Kraemer WJ. *Designing Resistance Training Programs.* Champaign, IL: Human Kinetics 2004.

9. Focht BC. Perceived exertion and training load during self-selected and imposed-intensity resistance exercise in untrained women. *The Journal of Strength & Conditioning Research* 21: 183-187, 2007.

10. Garhammer J. A review of power output studies of Olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *The Journal of Strength & Conditioning Research* 7: 76-89, 1993.

11. Gearhart Jr RE, 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. *The Journal of Strength & Conditioning Research* 16: 87-91, 2002.

12. Hackett DA, Johnson NA, Halaki M, and Chow CM. A novel scale to assess resistance-exercise effort. *J Sports Sci* 30: 1405-1413, 2012.

13. Jackson AS and Pollock ML. Generalized equations for predicting body density of men. *British Journal of Nutrition* 40: 497-504, 1978.

14. Kraft JA, Green JM, and Thompson KR. Session ratings of perceived exertion responses during resistance training bouts equated for total work but differing in work rate. *The Journal of Strength & Conditioning Research* 28: 540-545, 2014.

15. Lagally KM, Mccaw ST, Young GT, Medema HC, and Thomas DQ. Ratings of perceived exertion and muscle activity during the bench press exercise in recreational and novice lifters. *The Journal of Strength & Conditioning Research* 18: 359-364, 2004.

16. Lagally KM, Robertson RJ, Gallagher KI, Goss FL, Jakicic JM, Lephart SM, Mccaw ST, and Goodpaster B. Perceived exertion, electromyography, and blood lactate during acute bouts of resistance exercise. *Medicine and Science in Sports and Exercise* 34: 552-559; discussion 560, 2002.

17. Mann JB, Thyfault JP, Ivey PA, and Sayers SP. The effect of autoregulatory progressive resistance exercise vs. linear periodization on strength improvement in college athletes. *The Journal of Strength & Conditioning Research* 24: 1718-1723, 2010.

18. McBride JM, Blaak JB, and Triplett-McBride T. Effect of resistance exercise volume and complexity on EMG, strength, and regional body composition. *European Journal of Applied Physiology* 90: 626-632, 2003.

19. McNamara JM and Stearne DJ. Flexible nonlinear periodization in a beginner college weight training class. *The Journal of Strength & Conditioning Research* 24: 2012-2017, 2010.

20. Noble BJ and Robertson RJ. *Perceived Exertion.* Leeds, United Kingdom: Human Kinetics, 1996.

21. Pierce K, Rozenek R, and Stone MH. Effects of high volume weight training on lactate, heart rate, and perceived exertion. *The Journal of Strength & Conditioning Research* 7: 211-215, 1993.

22. Pincivero D, Lephart S, Moyna N, Karunakara R, and Robertson R. Neuromuscular activation and RPE in the quadriceps at low and high isometric intensities. *Electromyography and Clinical Neurophysiology* 39: 43-48, 1998.

23. Pincivero DM, Coelho AJ, and Campy RM. Perceived exertion and maximal quadriceps femoris muscle strength during dynamic knee extension exercise in young adult males and females. *European Journal of Applied Physiology* 89: 150-156, 2003.

24. Pincivero DM and Gear WS. Quadriceps activation and perceived exertion during a high intensity, steady state contraction to failure. *Muscle & nerve* 23: 514-520, 2000.

25. Pritchett RC, Green JM, Wickwire PJ, and Kovacs M. Acute and session RPE responses during resistance training: Bouts to failure at 60% and 90% of 1RM. *South African Journal of Sports Medicine* 21, 2009.

26. Row BS, Knutzen KM, and Skogsberg NJ. Regulating explosive resistance training intensity using the rating of perceived exertion. *The Journal of Strength & Conditioning Research* 26: 664-671, 2012.

27. Suminski RR, Robertson RJ, Arslanian S, Kang J, Utter AC, DaSilva SG, Goss FL, and Metz KF. Perception of effort during resistance exercise. *The Journal of Strength & Conditioning Research* 11: 261-265, 1997.

28. Sweet TW, Foster C, McGuigan MR, and Brice G. Quantitation of resistance training using the session rating of perceived exertion method. *The Journal of Strength & Conditioning Research* 18: 796-802, 2004.

29. Taylor R. Interpretation of the correlation coefficient: a basic review. *Journal of Diagnostic Medical Sonography* 6: 35-39, 1990.

30. Testa M, Noakes TD, and Desgorces F-D. Training state improves the relationship between rating of perceived exertion and relative exercise volume during resistance exercises. *The Journal of Strength & Conditioning Research* 26: 2990-2996, 2012.

31. Timmons JA. Variability in training-induced skeletal muscle adaptation. *Journal of Applied Physiology* 110: 846-853, 2011.

32. Tuchscherer M. The Reactive Training Manual: Developing your own custom training program for powerlifting. 2008.

33. USAPL and Administrators. I. *USAPL Rulebook and By-laws.*, 2001.

34. Vanderburgh PM and Batterham AM. Validation of the Wilks powerlifting formula. *Medicine and Science in Sports and Exercise* 31: 1869-1875, 1999.

35. Willardson JM, Norton L, and Wilson G. Training to failure and beyond in mainstream resistance exercise programs. *Strength & Conditioning Journal* 32: 21-29, 2010.

36. Willoughby DS. The effects of mesocycle-length weight training programs involving periodization and partially equated volumes on upper and lower body strength. *The Journal of Strength & Conditioning Research* 7: 2-8, 1993.

37. Zourdos MC. Physiological Responses To Two Different Models Of Daily Undulating Periodization In Trained Powerlifters, in: *Department of Nutrition, Food, and Exercise Science*. Tallahassee (FL): Florida State University 2012.

	ES (n=15)	NS (n=14)
Age (years)	24.4 ± 3.3	23.6 ± 3.2
Bodyweight (kg)	91.6 ± 19.3	80.3 ± 17.9
Height (cm)	176.8 ± 9.0	175.5 ± 8.9
Body Fat (%)	15.0 ± 5.1	17.6 ± 5.1
Training Age (years)	5.2 ± 3.5*	0.4 ± 0.6*
1RM (kg)	171.9 ± 50.9*	91.2 ± 25.5*
Wilk's Coefficient	114.8 ± 21.1*	66.0 ± 8.7*

Table 1.

	Mean ± 95% Confidence Interval		Median (Interquartile Range)	Median (Interquartile Range)
	ES (n=15)	NS (n=14)	ES (n=15)	NS (n=14)
RPE at 1RM*	9.80 ± 0.18	8.96 ± 0.43	10 (9.5-10)	9 (8.125-9.5)
RPE at 90% 1RM	7.87 ± 0.51	7.46 ± 0.70	8 (7.25-8.25)	7.75 (7-8)
RPE at 75% 1RM	5.18 ± 0.54	4.89 ± 0.70	5 (4.625-5.5)	5 (4-5.75)
RPE at 60% 1RM	3.54 ± 0.65	3.73 ± 0.56	4 (3-4)	4 (3-4)

Table 2.

* Data not normally distributed

	TRADITIONAL RELATIONSHIP	PROPOSED RELATIONSHIP			
		Experienced Squatters, n=15		Novice Squatters, n=14	
%1RM	Repetitions Allowed	95% CL RPE	Repetitions Allowed	95% CL RPE	Repetitions Allowed
100%	1	9.6-10.0	1	8.5-9.4	2-3
90%	4	7.4-8.4	3-4	6.8-8.2	3-4
75%	10	4.6-5.7	5-7+	4.2-5.6	5-7+
60%	-	2.9-4.2	8+	3.2-4.3	8+

Table 3.

RESISTANCE EXERCISE-SPECIFIC RATING OF PERCIEVED EXERTION (RPE)

Rating	*Description of Perceived Exertion*
10	*Maximum effort*
9.5	*No further repetitions but could increase load*
9	*1 repetition remaining*
8.5	*1-2 repetitions remaining*
8	*2 repetitions remaining*
7.5	*2-3 repetitions remaining*
7	*3 repetitions remaining*
5-6	*4-6 repetitions remaining*
3-4	*Light effort*
1-2	*Little to no effort*

Figure 1.

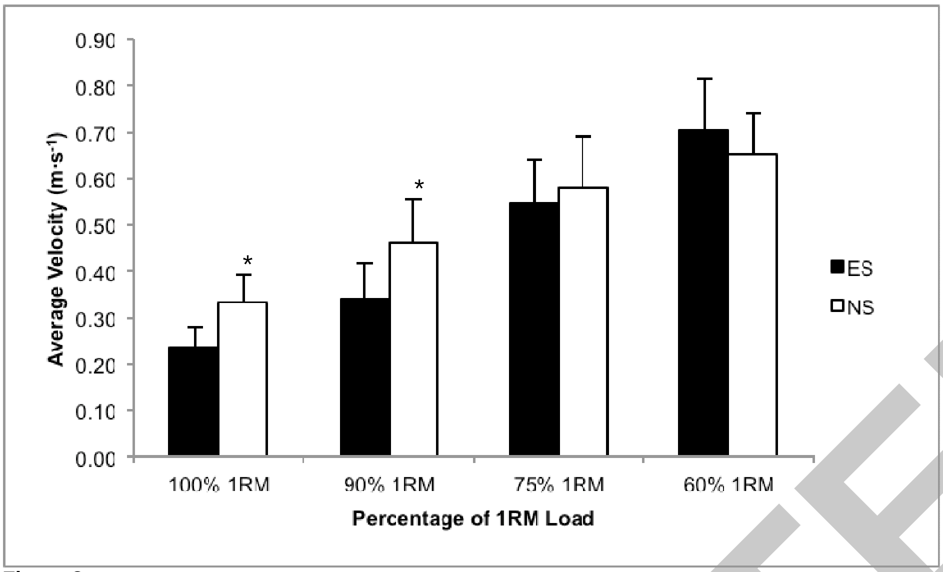
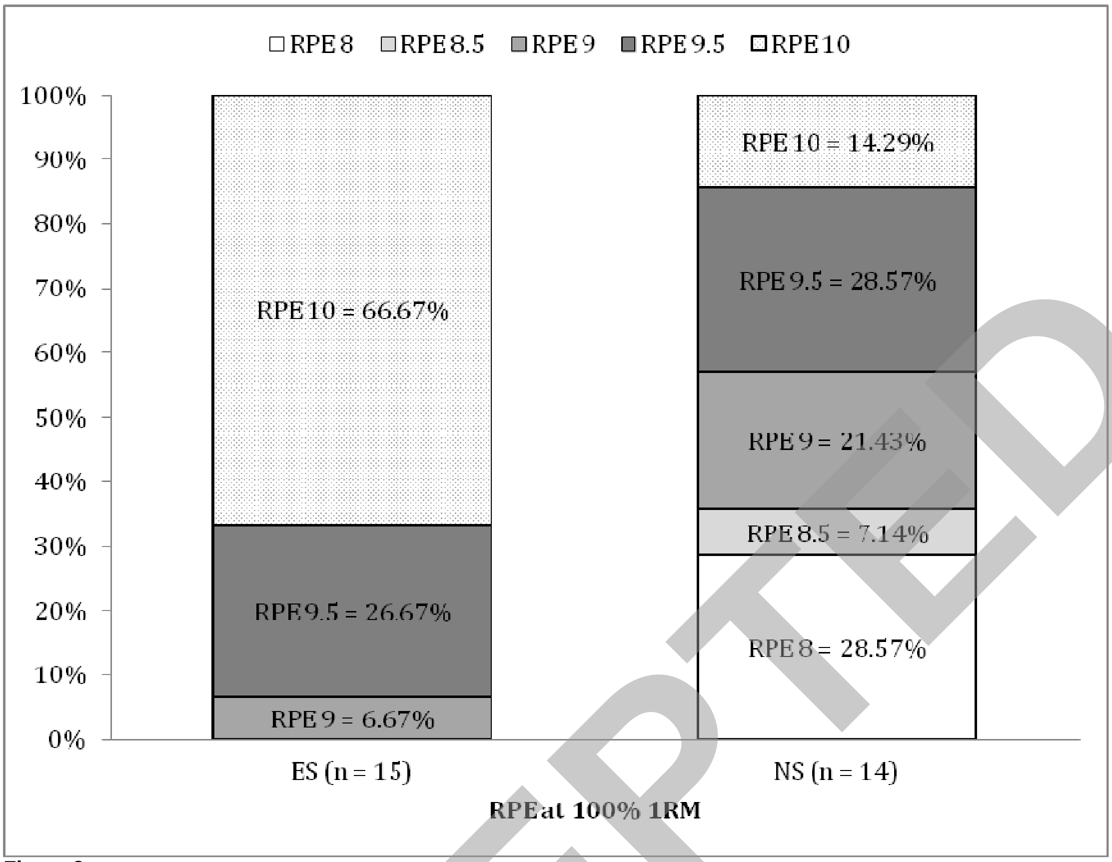

0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Average Velocity (m·s-1)
*
*
ES
NS
100% 1RM
90% 1RM
75% 1RM
60% 1RM
Percentage of 1RM Load

Figure 2.



RPE 8
RPE 8.5
RPE 9
RPE 9.5
RPE 10
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
RPE 10 = 66.67%
RPE 9.5 = 26.67%
RPE 9 = 6.67%
RPE 10 = 14.29%
RPE 9.5 = 28.57%
RPE 9 = 21.43%
RPE 8.5 = 7.14%
RPE 8 = 28.57%
ES (n = 15)
NS (n = 14)
RPE at 100% 1RM

Figure 3.