

ASSESSMENT OF ONE REPETITION MAXIMUM (1RM) AND 1RM PREDICTION EQUATIONS: ARE THEY REALLY NECESSARY?

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Abstract

Many well known resistance training authors and coaches believe that it is necessary to know an individual's actual 1RM or predicted 1RM for each specific exercise. They claim that the accuracy of prescribing effective resistance training protocols is dependent on this information. This systematic review challenges that widely held belief and presents compelling evidence to the contrary. There is a direct relationship within individuals between muscular strength and performing a maximal number of repetitions with a submaximal resistance. This relationship does not change with training and is more relevant to progressive strength gains than knowing the actual or predicted 1RM, which appears irrelevant.

Key words: muscular strength, resistance training, progression

Introduction: Assessment of One repetition Maximum (1RM)

A one repetition maximum (1RM) is the maximal amount of resistance that can be moved through the entire range of motion for a given exercise using a specific modality such as free weights, plate loading or selectorized weight machines. Most free weight exercises and some multiple joint machine exercises will have a sticking zone; that is, where the external torque (resistive torque) is greater than the internal torque (muscular torque) at specific points in the range of motion. Therefore, the sticking zone is the most difficult portion of the range of motion. Consequently, unless the trainee cheats (deviates from proper form) to move the resistance through the sticking zone, the 1RM is limited to the amount of resistance that can be moved through the sticking zone.

The primary objective of this systematic review is to challenge the necessity of actually testing or predicting the 1RM to evaluate strength gains.

Claims for Assessing or Predicting the 1RM

Some resistance training experts have claimed that it is important to know the 1RM or predicted 1RM so that a given percent of the 1RM can be used to maximize chronic adaptations such as an increase in muscular strength. For example, the current American College of Sports Medicine (ACSM) Position Stand on resistance training [1] claimed that specific percentages of the 1RM produce different strength gains for trainees with varying resistance training experience ranging from *novice* to *trained* to *athletes* (none of these classifications is clearly defined by the ACSM).

Consequently, the inference is that the 1RM or a predicted 1RM would be required to prescribe effective resistance exercise.

The ACSM [1] cited two reviews [2-3] in an attempt to support their opinion regarding strength gains as a result of training with a specific percent of the 1RM. Rhea and colleagues [2] claimed that training with 80% 1RM would produce a strength gain effect size in *advanced trainees* that is almost three times the effect size as training with 85% 1RM. An effect size is a standardized statistical estimate of how large or small the difference is between a pre-training and post-training variable such as strength gains or the difference between two or more groups for a specific variable. Peterson and colleagues [3] claimed that the effect size for strength gains in *athletes* was almost double when training with 85% 1RM compared with 80% 1RM, and that 75% 1RM produced an effect size ten times greater than training with 70% 1RM. These absurd claims by Rhea and colleagues, Peterson and colleagues, and the ACSM have been shown to have no known physiological basis for support and are without any scientific foundation [4-5]. It has been reported recently that different percents of the 1RM ranging from 40% 1RM to 90% 1RM and different ranges of repetitions such as 3-5, 6-8, 9-12, etc. have failed to elicit any significant difference in strength gains in the preponderance of resistance training studies [6].

In a Position Statement on youth resistance training [7], the National Strength and Conditioning Association (NSCA) recommended using 50-70% 1RM for *novice* trainees, 60-80% 1RM for *intermediate* trainees, and 70-85% 1RM for *advanced* trainees (Table 2, p.

S72). The authors did not cite any evidence to support their opinion that children should be required to know their 1RM for each exercise or train at different percents of their 1RM. These unsupported NSCA recommendations for a different status of training were based on the length of time training – not on the individual's level of strength or conditioning. In contrast, the American Academy of Pediatrics [8] warned that preadolescents and adolescents should avoid maximal lifts (1RM). They logically recommended beginning with a low resistance until proper technique is perfected with 8-15 repetitions and then gradually adding resistance in 5-10% increments.

Hatfield and colleagues [9] claimed that maximal strength gains required a resistance of 80-100% 1RM. They cited only a book [10] and a review [11] in an attempt to support their claim. Other extensive reviews by authors such as Fry [12], Crewther and colleagues [13] Kraemer and Fragala [14], and Kraemer and Ratamess [15] also recommended – without any supporting evidence – specific training loads (percent 1RM) for specific adaptations in different populations.

From a practical aspect, prediction equations would require trainers and coaches to know a multitude of equations, which would depend on the equipment used for each specific exercise, and the age, sex, and training experience of each trainee. If the training modality changes, such as switching from machines to free weights or using another training facility with different equipment, new equations would have to be applied for each exercise. For example, Cotterman and colleagues [16] reported a significantly greater 1RM when the bench press and squat exercises were assessed with a Smith machine compared with free weight exercises in 32 young males and females with at least one year of resistance training experience. Lyons and colleagues [17] assessed the 1RM in 31 young male subjects who had an average of 4.3 years of resistance training experience. The 1RM was significantly greater on all the plate loading Hammer strength machines compared with free weight exercises: bench press, overhead press, and biceps curl. In addition, as trainees increase their strength, they would have to be reevaluated on a regular basis to maintain the specific percent of the 1RM. Either of these common occurrences would require a time consuming evaluation of repetitions to fatigue or an actual 1RM assessment.

Summary

Despite these primarily unsupported opinions regarding the importance of knowing the actual or predicted 1RM to prescribe training resistance, researchers spend countless hours conducting prediction and validation studies, and many coaches, trainers and trainees spend countless hours assessing or predicting the 1RM.

1RM Prediction Equation Studies

There are several studies [18-25] that have developed equations to predict the 1RM (one repetition maximum) for various upper and lower body exercises with free weights and machines. Equations for predicting the 1RM are derived from the performance of a maximal number of repetitions for a specific exercise with some arbitrarily determined absolute submaximal resistance (e.g., 50 kg) or a specific relative submaximal load such as an 8RM. An 8RM is the amount of resistance that can be performed for eight repetitions, with the inability to perform a ninth repetition. The set is continued until the subject is unable to complete the concentric phase of the repetition. Based on the number of completed repetitions, regression analysis is performed and equations are developed in an attempt to predict the 1RM.

Validation Studies of 1RM Prediction Equations

Subsequent studies have attempted to validate these prediction equations for populations of different age, sex and resistance training experience. Some of these validation studies [26-38] have compared the actual 1RM with several prediction equations. For example, Knutzen and colleagues [34] compared six equations for 11 upper and lower body machine exercises ($r = .60-.90$), Le Suer and colleagues [35] compared seven prediction equations for the free weight squat, bench press and deadlift ($r = .96-.99$), Ware and colleagues [37] compared four equations for free weight bench press and squat ($r = .67-.95$), and Whisenant and colleagues [38] compared 12 equations for the free weight bench press ($r = .84-.93$).

Summary

A discussion of the validity of these predictions equations and their correlations with the actual 1RM, which varied considerably depending on the exercise, equation, and the population of the participants, is beyond the scope of this review and has been previously addressed in numerous validation studies [26-38] and reviews [39-42]. The primary question in this review is whether these time consuming 1RM assessments or any of the 1RM prediction equations are ever required.

Familiarization and Testing the 1RM

An important consideration if attempting to assess the 1RM is that it may require several time consuming familiarization and testing sessions for each exercise to obtain an accurate 1RM. For example, Ritti-Dias and colleagues [43] assessed the 1RM free weight bench press and Smith machine squat in 14 young novice male trainees and 16 young males with an average 35 months of resistance training experience. All the subjects attended one orientation and four testing sessions, which were separated by 48-72 hours. Each

test session consisted of a warm-up set of 6-10 repetitions with approximately 50% of the estimated 1RM for each exercise and 3-5 minutes rest between each of the 1RM attempts. The authors did not report the number of attempts required to obtain the 1RM. There was a significant increase in 1RM bench press (~10%) between the 1st and 4th testing session and a significant increase (~11%) for 1RM squat between the 1st and 4th sessions in the novice trainees. The absolute difference in 1RM was approximately 5.3 kg and 11.7 kg between the 1st and 4th test sessions, bench press and squat, respectively. There was no significant difference in 1RM between any of the sessions in the experienced group for either exercise. The authors concluded that novice trainees required 2-3 1RM testing sessions for each exercise to accurately assess muscular strength.

Cronin and Henderson [44] assessed the unilateral and bilateral 1RM leg press and Smith machine bench press in 10 athletic young males who had not performed resistance exercise at least six months prior to this study. Each 1RM session included a warm-up for each exercise that was described as a progressive overload on the involved musculature, but the authors did not report the specific warm-up protocol. There were 2-3-minute inter-set rest intervals for the warm-up sets and three minutes rest between each attempted 1RM. If a subject did not obtain a 1RM within six attempts, they returned for another session to complete the assessment. The four 1RM sessions were separated by 7-10 days. The 1RM leg press significantly increased from the 1st to the 4th assessment (16.8% and 15.0%, unilateral and bilateral 1RM, respectively), which in absolute values was approximately 20 kg and 30 kg, respectively. Bench press 1RM significantly increased 13.6% (~10 kg) from the 1st to the 4th session. The authors concluded that these significant changes in 1RM occurred in the absence of any formal resistance training program and 1RM assessments in novice trainees must occur over multiple trials to ensure validity.

Ploutz-Snyder and Giamis [45] tested the seated bilateral knee extension 1RM in seven young and six older females with no previous resistance training. The warm-up consisted of 10 repetitions with a light resistance and five repetitions with a medium resistance before 3-8 attempts at the 1RM. There were two minutes rest between the 1RM trials. Subjects returned for additional 1RM sessions until the difference in 1RM between sessions was not greater than 1 kg. The older females required more than twice as many sessions (7-10) as the younger females (2-5) to establish the 1RM. The percent increase (22.5%) in 1RM from the first to the last session was significantly greater in the older females compared with the younger females (12.5%). The authors concluded that the older subjects required more practice and familiarization than the younger subjects to obtain a valid 1RM.

Abad and colleagues [46] recruited 13 young males who regularly performed the leg press exercise twice a week for approximately 18 months. The researchers wanted to compare the 1RM leg press after either a specific warm-up or a combination of a general warm-up and specific warm-up. After a familiarization session, which included a *simulated* 1RM to estimate the resistance for the actual 1RM testing sessions, the participants were tested for the 1RM in a random crossover design. One of the 1RM assessments was performed after a specific warm-up that consisted of eight repetitions with 50% of the estimated 1RM and three repetitions with 70% 1RM. After the specific warm-up, they had up to five attempts to obtain the 1RM. Another 1RM assessment was scheduled after a minimum of seven days. The other session began with a general warm-up (20 minutes cycling at 60% HR_{max}) followed by the previously mentioned specific warm-up. The combination warm-up procedure provided a 1RM that was significantly greater (8.4%) than the specific warm-up alone. This was approximately a 30 kg difference in resistance. The authors concluded: *"Our results suggest that moderate intensity general warm-up routines should be performed in association with specific warm-up before maximum strength assessments to improve performance, but more importantly to obtain accurate maximal strength assessments"* (p. 4).

None of these studies [43-46] controlled for repetition duration during the 1RM assessments. However, they do strongly suggest that some familiarization and multiple 1RM testing are required for a valid assessment of the 1RM. These studies in previously untrained [43-45] and trained [46] participants clearly demonstrate the inordinate amount of time required for trainers and trainees to assess the 1RM for each exercise and the extensive time to perform all these warm-up rituals – especially the combination of a general plus a specific warm-up suggested by Abad and colleagues [46] – and 1RM assessments for each exercise every time one wishes to estimate strength gains.

Summary

Trainers and trainees may want to decide if the reported significant 10.0-16.8% difference (~5-30 kg) as a result of multiple 1RM testing sessions would be more or less accurate than using the percent increase in resistance for a specific range of repetitions. Although there is a lack of research to show how many sessions are required to assess accurately the maximal possible number of repetitions for 1RM prediction equations or to establish the correct resistance for a specific range of repetitions at a particular repetition duration, the difference is that establishing the resistance for a desired range of repetitions for each exercise would be included in the training program and not require additional time consuming sessions.

Repetition Duration

Repetition duration is the time to complete each phase of a repetition. For example, a repetition that consists of a 3-second concentric phase and 3-second eccentric phase is considered a 3s:3s repetition duration. Unfortunately, repetition duration is rarely – if ever – controlled when assessing the 1RM or during the performance of a maximal number of repetitions. With the exception of one prediction study by Abadie and colleagues [18] and one validation study by Kim and colleagues [33], none of these 1RM prediction or validation studies [18-38] has controlled for repetition duration during the 1RM assessment or during the performance of multiple repetitions with a sub-maximal resistance. Failure to control for repetition duration raises the question of the practical application of these prediction equations. Several studies [9, 47-52] have shown that the number of completed repetitions is greater with shorter repetition duration (faster movement) than with longer repetition duration (slower movement).

Hatfield and colleagues [9] reported the influence of repetition duration on the maximal number of repetitions for the Smith machine squat and military press exercises. The nine young male subjects had at least one year of resistance training that included these two exercises. They performed as many repetitions as possible with 60% and 80% of their 1RM using two repetition durations: self-selected and 10s:10s. A metronome was used to guide the 10s:10s protocol but the authors did not report the self-selected repetition duration. Each exercise was terminated when the subject could no longer complete a repetition, maintain the 10s:10s duration, or exercise technique was compromised. The number of completed repetitions was significantly greater for the self-selected repetition duration compared with the 10s:10s duration for both exercises. For example, at 80% 1RM the number of completed repetitions was approximately six times greater with the self-selected repetition duration for both exercises (~6 reps compared with ~1 rep, and ~12 reps compared with ~2 reps, military press and squat, respectively; Figure 1, p. 762).

LaChance and Hortobagyi [47] tested 75 moderately trained young males for the maximal number of push-ups and pull-ups at three repetition durations: self-paced (~1.2s and ~2.6s, push-ups and pull-ups, respectively, which was the total time for the concentric and eccentric muscle actions), 2s:2s (concentric and eccentric muscle actions, respectively), and 2s:4s. The exercise was terminated when the subject was unable to maintain the prescribed repetition duration. It should be noted that LaChance and Hortobagyi, and others in the resistance training literature, incorrectly referred to the 2s:2s repetition duration as the *cadence*. The cadence was actually 15 repetitions per minute

(60s / 4s = 15). There was a significant difference in the number of completed repetitions among the three repetition durations, with shorter durations eliciting the greater number of repetitions (self-paced > 2s:2s > 2s:4s) for both the push-up and pull-up exercises.

Pereira and colleagues [48] assessed nine physically active young males and females for the maximal number of completed repetitions performed on a conventional weight training knee extension machine. The faster speed (80°s^{-1}) produced a significantly greater maximal number of repetitions than the slower speed (25°s^{-1}) with both a lighter (60% 1RM) and heavier (80% 1RM) resistance. Pereira and colleagues astutely noted that this is probably because once inertia is overcome with the faster speeds (shorter repetition durations), the momentum is greater than with slower speeds (longer durations). Therefore, the force required to move the resistance through the remainder of the range of motion is reduced with shorter repetition durations. These results are supported by their two previous studies with the bench press and squat exercises [49-50], which also showed that shorter repetition durations compared with longer durations resulted in a greater number of completed repetitions.

Headley and colleagues [51] assessed 29 young males with at least two years of resistance training experience for 1RM bench press. Twelve of those participants then performed as many repetitions as possible with 75% of their 1RM. All the participants used two different repetition durations (2s:2s and 2s:4s) during both assessments. The 1RM was significantly greater with the shorter repetition duration. The subjects who were assessed with 75% 1RM completed a significantly greater number of repetitions when they used the shorter repetition duration protocol.

Sakamoto and Sinclair [52] reported the effect of different repetition durations on the number of completed bench press repetitions. Thirteen young males with approximately four years of resistance training experience performed the maximal number of repetitions with 40, 50, 60, 70 and 80% of their predetermined 1RM on a Smith machine. Using each of these five amounts of resistance, the subjects exercised at four different repetition durations: 2.8s:2.8s (longer), 1.4s:1.4s (medium), 1.0s:1.0s (shorter), and ballistic repetitions where the subjects threw the bar upward as rapidly as possible. They were not permitted to bounce the bar on their chest and performed each set to the point where complete elbow extension was not possible. The number of completed repetitions was significantly greater with the shorter repetition durations (ballistic and shorter > medium > longer) with all the aforementioned percents of the 1RM.

In their Practical Applications section Sakamoto and Sinclair [52] noted that when a training load is estimated from the percent 1RM, training with the intended load

is dependent on the specific repetition duration. The example they presented was that a 10RM with the longer duration repetition equaled ~56% 1RM and with the shorter duration the resistance was ~70% 1RM. Sakamoto and Sinclair concluded: "*This study clearly showed that the relationship between intensity and the number of repetitions was affected by movement velocity and that a faster velocity [shorter repetition duration] resulted in more repetitions being performed*" (p. 526). Furthermore: "*The practical applications of this study are that, when trainees are assigned resistance training with specific RM values, the lifted intensity (% 1RM) or weights will not be consistent unless velocity [repetition duration] is controlled during training*" (p. 523).

Force-Velocity Curve

A basic concept in resistance training exercise physiology is the relationship between the force a muscle produces and the speed at which it is able to shorten; that is, a slower speed of shortening is related to a greater force. The aforementioned repetition duration studies [9, 47-52] would at first appear to contradict this widely accepted physiological concept because the subjects were generating a greater force, or performing a greater number of repetitions at faster speeds of movement (shorter repetition durations). However, the classic in-vitro force-velocity curve is established from an isolated muscle fiber that is secured on one end and has a given mass on the other end. When the fiber is electrically stimulated, a smaller mass allows the fiber to shorten faster. A larger mass decreases the speed of shortening. An in-vivo force-velocity curve is plotted on an isokinetic accommodating resistance exercise machine – with inherently very low mass and momentum. A faster speed of movement results in a lower force output, and vice versa.

Summary

Because of momentum, these classic in-vitro and in-vivo isokinetic force-velocity curves have very little practical application when the resistance has any significant mass such as with free weights, plate loading or weight stack machines. Greater speed of movement (shorter repetition duration) produces greater momentum, which helps to move the resistance through the range of motion; that is, the momentum makes it easier to perform the exercise.

Intra-Set Repetition Duration

There are several studies to suggest that the repetition duration significantly increases as a set progresses. Izquierdo and colleagues [53] evaluated 36 young males who had been resistance training with free weights (including the bench press and squat) for 15 months preceding this study. The participants were assessed for their 1RM and the performance of as many

repetitions as possible with 60, 65, 70 and 75% 1RM on the bench press and squat exercises. The tests were all performed on a Smith machine (the barbell secured on both ends) and the subjects were instructed to perform the concentric phase of all repetitions (including the 1RM) as rapidly as possible. The repetition duration was significantly longer on the last repetition of each set compared with the initial two repetitions for both exercises at 60, 65, 70 and 75% 1RM. The repetition duration of the last repetition of each set was not significantly different from the repetition duration of the 1RM for both exercises.

Sanchez-Medina and Gonzalez-Badillo [54] assessed 18 young males who had at least 3-5 years of resistance training experience for 1RM barbell bench press and squat on a Smith machine. The participants then performed as many repetitions as possible with 70, 75, 80, 85 and 90% 1RM. The concentric phase was measured with a linear transducer and custom computer software and the subjects were instructed to perform the concentric phase of each repetition *in an explosive manner at maximal possible velocity*. Because of fatigue, there was a significant increase in concentric repetition duration from the first to the final repetition of all sets for both exercises. The authors did not define or report the duration of the eccentric phase of each repetition (described as the *normal controlled speed*). They concluded that their study confirms an increased repetition duration as the number of repetitions in a set approaches the maximum number.

Lawton and colleagues [55] reported the power output for a 6RM free weight bench press in 26 young males who had at least seven months of resistance training experience. A linear encoder was attached to the barbell and relayed the data to a data acquisition and analysis computer program. Participants were instructed to perform the concentric phase of each repetition as explosively as possible. There was a significant increase in repetition duration between each continuous successive repetition and a 53% increase between the first and sixth repetitions.

Duffy and Challis [56] assessed 10 males and eight females for their 1RM free weight bench press after completing a 14-week resistance training class. After the 1RM, the subjects performed as many repetitions as possible with 75% 1RM. A 2-camera Qualysis Pro-Reflex system was used to record the movement of reflective markers on the barbell and the subject. The time to lift the resistance was significantly greater – more than double – on the last repetition compared with the first repetition. The repetition duration on the final repetition with 75% 1RM was not significantly different from the duration of the actual 1RM. The authors reported the mean number of repetitions was 10 with 75% 1RM, but the range was 4-16 repetitions. This inter-individual variability demonstrated

the wide range of repetitions among individuals for the identical free weight bench press exercise – and therefore emphasizes the difficulty of a general prescription for a range of repetitions based on a specific percent 1RM.

Summary

The preponderance of evidence suggests that maximal motor unit activation is primarily dependent on the amount of effort at the end of a set of repetitions (see references 6 and 57 for an extensive list of supporting evidence). Therefore, despite the intention to move the resistance as quickly as possible on every repetition, the maximal effort and perhaps the greatest stimulus for motor unit recruitment occurs during repetitions with relatively longer repetition durations.

Potential Orthopedic Injuries

The potential for orthopedic injuries exists during 1RM assessments. Pollock and colleagues [58] reported that 19.3% of his elderly male and female participants sustained injuries during their 1RM assessment of one upper body and one lower body exercise. In contrast, Shaw and colleagues [59] reported only 2.4% injury rate in elderly males and females who performed the 1RM for three upper body and two lower body exercises, and Rydwike and colleagues [60] reported no injuries in elderly males and females who were assessed for 1RM pull-down. Much less is known about the orthopedic risks of 1RM assessments or performing maximal number of repetitions with a submaximal resistance in a younger or middle aged healthy population.

Faigenbaum and colleagues [61] assessed the 1RM in 64 males and 32 females between the age of 6.2 and 12.3 years who had no previous experience with resistance training or strength testing. Approximately half the subjects were assessed with the standing chest press and knee extension exercise, and the others for seated chest press and leg press. All the testing was performed on scaled down child-size plate loading machines, which were similar in design to adult-size machines. There were no injuries during the 1RM assessments and no reports of severe muscle soreness. The authors concluded that 1RM testing can be safely performed in children provided that appropriate testing guidelines are followed. They did state however, that they could not draw any conclusions regarding the chronic effects of maximal lifts on bone tissue or bone growth, nor on the safety of testing children on other types of equipment such as free weights. Because the strength gains are similar for different ranges of repetitions [6], the alternative to any risk of 1RM assessments in any age group is simply to choose a preferred range of repetitions (e.g. 6-8, 9-12, etc) and use the increase in resistance for that range of repetitions to determine

strength gains. This training concept is discussed in a subsequent section of this review.

Summary

There are extensive reviews on safety considerations of 1RM assessments such as by Niewiadomski and colleagues [62]. The aforementioned studies [59-61] suggest that if the assessments are properly controlled for exercise form, the risk of orthopedic or soft tissue injury is minimal in a healthy population. However, again the primary question is whether these assessments are really necessary.

Blood Pressure Responses to 1RM Assessments and Maximal Number of Repetitions

One of the concerns regarding the assessment of 1RM or predicting the 1RM by performing as many possible repetitions with a submaximal resistance is that the maximal effort in either assessment elicits very high intra-arterial systolic and diastolic blood pressure responses as compared with resting levels – even in trainees with normal resting blood pressure [63-68]. For example, MacDougall and colleagues [63] reported peak blood pressure responses of 320/250 mmHg during the final repetitions of a bilateral leg press exercise with 95% 1RM. The arterial pressure response to the maximal number of repetitions with 95% 1RM bilateral leg press was significantly greater than the 1RM bilateral leg press (275/205 mmHg).

Despite the highly elevated blood pressure responses to resistance exercise, Gordon and colleagues [69] reported on 5,460 males and 1,193 females ranging in age from 20-69 years who were patients at the Cooper Clinic. They assessed the 1RM bench press and leg press on a variable resistance Universal machine. Although the comprehensive medical examination that preceded the testing may have screened out those at risk for any cardiovascular complications, none of the 6,653 patients experienced a clinically significant fatal or nonfatal cardiovascular event during the strength testing.

Rating of Perceived Exertion

Several studies have reported the rating of perceived exertion (RPE) immediately after a set of resistance exercise. These studies compared the RPE with different amounts of resistance [70-74], resistance and repetition durations [75], inter-set rest intervals [76], and compared RPE with electromyographic muscle activity [77-78]. However, there is a lack of any evidence to support a relationship between RPE and direct intra-arterial measurement of blood pressure responses during the final few repetitions of a set.

Consequently, the only practical way to estimate blood pressure responses during a set of resistance exercise is to use the indirect auscultatory method with a sphygmomanometer. Because of the rapid return

of blood pressure to resting levels immediately post-exercise (within 10 seconds), the auscultatory assessment should be performed toward the end of the set during the last few repetitions. This procedure can be challenging for a trainer or coach and is rarely practiced. Without accurate blood pressure measurements, it is not known when to terminate a set of repetitions in a specific person – especially hypertensive trainees.

Summary

Intra-arterial studies on the acute blood pressure responses to resistance exercise [63-68] showed that the 1RM appears to be less of a stress on the cardiovascular system than performing a maximal number of repetitions with a submaximal resistance. There is a lack of evidence to suggest that this cardiovascular stress is a major concern in a healthy population of trainees.

Relationship between 1RM and Submaximal Resistance in Untrained and Trained Subjects

There are several resistance training studies [27, 66, 79-83] that specifically reported the relationship between the 1RM and relative muscular endurance. Relative muscular endurance refers to the performance of a maximal number of repetitions with an equal percentage of the pre-training and new post-training 1RM.

Brechue and Mayhew [27] evaluated 58 collegiate male football players for their 1RM and repetitions to failure (RTF) at 60, 70, 80, and 90% 1RM for the free weight bench press. The participants trained four days a week (2 upper body and 2 lower body sessions) for 12 weeks. The average bench press 1RM significantly increased ~10 kg for the whole group. There were no significant changes in RTF for any percent (60, 70, 80 or 90%) of the actual post-training 1RM. For example, RTF was 20.0 and 19.9 at 60% 1RM, 12.6 and 12.8 at 70% 1RM, 9.0 and 8.7 at 80% 1RM, and 3.8 and 3.5 at 90% 1RM, pre-training and post-training, respectively. The authors noted that the resistance used for the RTF (60, 70, 80, and 90% of the actual 1RM) increased in direct proportion to the increase in 1RM. Brechue noted that trainees could use a selected range of repetitions and would not have to actually assess or predict the 1RM because the changes in resistance used for that specific range of repetitions would be indicative of the strength gains (personal communication with Dr. Brechue, 08-10-10).

Sale and colleagues [66] reported a primarily unchanged pre-training to post-training individual relationship between 1RM and multiple repetitions with a submaximal resistance. Muscular failure occurred at a similar number of repetitions (18.2 and 18.5, 15.4 and 15.4, 13.4 and 11.8, pre-training and post-training, respectively) with 80, 85 and 87.5% 1RM, respectively. Sale and colleagues stated: “The

absolute weight lifted after training at 50, 70, 80, 85 and 87.5% 1-RM increased by an amount [26, 26, 25, 27, and 26%, respectively] corresponding to the increase in 1-RM after training (~26%, $P < 0.01$)” (p. 64).

Hickson and colleagues [79] trained eight previously untrained young males and females three times a week for 16 weeks. The participants performed five sets with 80% 1RM for the free weight bench press and parallel squat exercises, and five sets of 5RM for the knee extension, knee flexion and triceps pushdown exercise on a Universal machine. All the exercises were performed to a cadence of 13 repetitions per minute (4.6s total repetition duration for combined concentric and eccentric muscle actions), with two minutes rest between sets. They assessed the 1RM bench press and squat pre-training and post-training and the maximal number of repetitions with 40, 60 and 80% 1RM at the new post-training relative resistance, which corresponded to the same relative resistance (percent of the 1RM) as before training. The authors described the guidelines for stopping the testing as the inability to complete a repetition or the inability to maintain the repetition duration.

There was a significant increase in 1RM bench press (23%) and squat (37%), with no significant difference in the relative increase between males and females [79]. At the same relative workload (40, 60 and 80% of the post-training 1RM), there was no significant difference in the number of completed repetitions for either the bench press or squat exercises pre-training to post-training. For example, at 80% 1RM the subjects completed 7.6 and 7.1 repetitions in the bench press, and 8.0 and 8.7 repetitions in the squat, pre-training and post-training, respectively (Table 2, p. 595). The authors also compared the number of bench press repetitions between the subjects with the highest and lowest strength levels. At 80% 1RM there was no significant difference in the number of completed repetitions between these two subgroups either before or after training. Hickson and colleagues [79] concluded: “Our data clearly show that strength-dependent submaximal performance at low to high intensities [percent 1RM] is neither compromised nor enhanced following a strength regimen” (p. 596).

Fish and colleagues [80] compared the DeLorme and Oxford resistance training techniques in 38 middle-age females and 12 middle-age males who had no previous resistance training experience. Both protocols consisted of three sets of 10 repetitions. In the DeLorme protocol, the 1st set is 50% 10RM, the 2nd set 75% 10RM, and the 3rd set is with the 10RM. The Oxford protocol uses a reverse sequence beginning with the 10RM for the 1st set, 75% 10RM and 50% 10RM for the 2nd and 3rd sets respectively. All participants trained the unilateral knee extensors with a DeLorme boot three times a week for nine weeks. Both groups

significantly increased the 1RM and 10RM, with no significant difference between the DeLorme and Oxford technique. There was no significant difference in the percent increase between the 1RM and 10RM in the DeLorme group (96.5% and 105.5%, respectively) and identical increases in 1RM and 10RM (81.5%) in the Oxford group.

Mayhew and colleagues [81] recruited 70 males and 101 females from a collegiate fitness class to participate in a 14 week resistance training program. The subjects progressively increased the resistance within the range of 5-10 repetitions three times a week. Exercises with free weights, Nautilus and Hydra-Gym machines involved upper and lower body muscle groups. The 1RM free weight bench press and the number of completed repetitions were assessed pre-training and post-training. The percent of each subject's 1RM (designated as the *REP* weight) was determined from a specifically designed random numbers program, which ranged from 55%-95% 1RM. The same percentage of the pre-training 1RM was used for the post-training 1RM to assess the number of completed repetitions. They did not control for repetition duration but most of the trainees reached a point of muscular fatigue within one minute. The males significantly increased their 1RM and the *REP* weight approximately 15% and the females approximately 26% (Table 1, p. 198). The number of completed repetitions for the males (at ~78% 1RM) was 10.8 and 11.0, pre-training and post-training, respectively; the females completed 12.4 and 12.6 repetitions, respectively, with ~76% 1RM. There was a significant percent increase in the *REP* weight for the males and females that was not significantly different from the increase in 1RMs. Mayhew and colleagues noted that their results strongly suggested that the relationship between the number of completed repetitions and percent 1RM is relatively constant and unaffected by training. They concluded: "...repetitions with a submaximal weight can be used to gauge improvements in upper body strength without detracting from workout time or effort" (p. 200).

Sebelski and colleagues [82] trained 59 young males on Nautilus machines and free weights three times a week for 14 weeks. The participants performed one set of 8-12 repetitions for each of seven upper and lower body exercises, including the free weight bench press. The 1RM bench press and the maximal number of repetitions with 60% 1RM (relative muscular endurance) were assessed pre-training and post-training. There was a significant increase in 1RM and the absolute resistance used to measure muscular endurance. The number of completed repetitions was not significantly altered with training (22.8 and 22.9 repetitions, pre-training and post-training, respectively). The authors concluded: "Despite the significant increase in strength, there was no significant change in

relative muscular endurance using a load equivalent to 60% of the 1-RM" (p. 75).

Miranda and colleagues [83] randomly assigned 20 young males with an average 4.8 years of resistance training experience to a linear periodization (LP) group (3 sets of 8-10RM, weeks 1-4, 3 sets of 6-8RM, weeks 5-8, and 3 sets of 4-6RM, weeks 9-12) or a daily undulating periodization (DUP) group, which varied the aforementioned loads (RMs) from session to session for the 12 weeks. Both groups performed nine exercises on Mondays and Thursdays and nine different exercises on Tuesdays and Fridays. The variation in the amount of resistance (RM) for both groups was on the leg press and bench press, and these two exercises were assessed for pre-training to post-training 1RM and 8RM. Three sets of 6-8RM were employed for all the other exercises throughout the 12 weeks. Although the researchers did not control repetition duration during the testing or training, all the exercises were performed to *voluntary concentric failure*. There was a significant increase in 1RM and 8RM bench press and leg press for both the LP and DUP groups, with no significant difference between groups for any measured variable. There was a similar significant percent increase in the 1RM and 8RM for the bench press and leg press, with no significant difference between the increase in 1RM and 8RM in either group. For example, there was a significant 15% and 18% increase for the bench press (1RM and 8RM, respectively) in the LP group and a significant 16% and 19% increase in the DUP group (1RM and 8RM, respectively). These results strongly suggest that the pre-training to post-training percent change in 8RM is a good indicator of strength gains and eliminates the necessity of testing or predicting the 1RM.

There is one study that reported results contrary to the seven aforementioned studies [27, 66, 79-83]. Braith and colleagues [84] recruited 23 sedentary young males to perform one set of 7-10RM bilateral knee extension exercise 2-3 times a week for 18 weeks. Repetition duration was 2s:4s. The participants' 1RM and 7-10RM were assessed pre-training and post-training. The training group significantly increased their 1RM 31.7% and 7-10RM 51.4%. The authors claimed that the resistance training altered the relationship between maximal and submaximal strength. Consequently, they warned that the level of training should be considered when estimating 1RM from multiple repetition tests. Perhaps these conflicting results were because Braith and colleagues tested a range of repetitions (7-10RM) rather than the 7RM or a specific percent of the 1RM.

Cross-Sectional Studies

Another study that is often cited to challenge the relationship between 1RM and repetitions performed

to fatigue (relative muscular endurance) is a cross-sectional study by Hoeger and colleagues [85]. They assessed 25 resistance trained young males, 40 untrained middle-aged females, and 26 trained young females. The resistance training experience in the trained groups ranged from two months to four years. They determined the 1RM on seven upper and lower body Universal machine exercises. On separate days, the subjects performed the maximal number of repetitions at 40, 60 and 80% 1RM in random order for each exercise. The results indicated that the number of repetitions performed at a specific percent of the 1RM were not the same for all the exercises in the trained versus the untrained males and trained versus untrained females. The data included untrained young males from a similar previous investigation [86]. However, some of the differences between groups were not significant but there were significant differences between some exercises. For example, at 60% 1RM there was no significant difference in the number of repetitions on the leg press exercise for untrained and trained males, but there was a significant difference between those groups for the thigh curl. The greater differences were between these two exercises in each group: 33.9 and 11.2 repetitions for the leg press and thigh curl, respectively in the untrained males; and 45.5 and 15.4 repetitions for the leg press and thigh curl, respectively in trained males (Table 3, p. 51).

Another example was that with 80% 1RM there was no significant difference in the number of repetitions in the leg press between trained and untrained females, but there were significant differences between the leg press and knee extension exercises in both trained and untrained females (Table 4, p. 52). In addition, there was no significant difference between trained and untrained males for the bench press or leg press – two commonly used exercises for evaluating upper and lower body strength – with submaximal loads of 40, 60 or 80% 1RM (Table 5, p. 53). Hoeger and colleagues [85] concluded: *“According to these results, strength training participants can no longer assume that a given number of repetitions is always associated with the same percent 1RM for all lifts. Neither can the prediction of the 1RM be generalized across individuals or exercises based on a number of repetitions performed”* (p. 50). It also is important to remember that this was not a training study; it was a cross-sectional study. Therefore, there is no evidence to suggest that any significant differences reported between groups were caused by progressing from a previously untrained to a trained status.

Since the study by Hoeger and colleagues [85] was published, other researchers have reported a positive relationship between 1RM and relative muscular endurance in cross-sectional studies. For example Kraemer and colleagues [87] compared acute hormonal

responses in 12 previously untrained young males and seven young competitive male powerlifters. They assessed the 1RM leg press and the number of completed repetitions with 80% 1RM. Not surprisingly, the 1RM was significantly greater in the powerlifters (299.5 kg) compared with the untrained group (156.0 kg). Despite a 92% greater 1RM in the powerlifters, the number of completed repetitions with 80% 1RM was not significantly different between the powerlifters (21.0 repetitions) and the previously untrained group (20.3 repetitions).

Huczel and Clarke [88] assessed 15 previously untrained young females and 15 young females with at least one year of resistance training experience. The isometric strength of the elbow flexors was 34% greater in the resistance trained group. However, there was no significant difference between the groups in relative muscular endurance (rhythmic isometric muscle actions).

Shimano and colleagues [89] recruited eight previously untrained young males and eight resistance trained young males who had at least six months experience training with the free weight squat, bench press, and arm curl exercises. They assessed the 1RM on the three exercises and on separate occasions performed as many repetitions as possible for each exercise with 60, 80 and 90% 1RM. All the exercises were performed at *volitional* repetition duration, although it was not specifically reported. The only significant difference in the number of completed repetitions between groups was the bench press exercise with 90% 1RM (6.0 and 4.0 repetitions, untrained and trained groups, respectively). Despite an approximately 60% greater mean 1RM for the trained subjects, there were no other significant differences between the trained and untrained subjects in the number of completed repetitions at each percent 1RM for all three exercises. Unfortunately, the authors' conclusions that greater than 90% 1RM should be used for strength gains and that athletes should be regularly assessed for their 1RM were not supported with any references and are without any scientific foundation.

Summary

Most of the previously discussed resistance training studies [27, 66, 79-83] and cross-sectional studies [87-89] support the concept of an unaltered specific relationship between 1RM and relative muscular endurance for each specific exercise in different individuals. Only one training study by Braith and colleagues [84] reported contrary results. Therefore, changes (increases) in the resistance used for training can provide an accurate indication of strength gains for that specific exercise. For example, if an individual is training the bench press exercise with a 6-8RM (e.g., 50 kg) and the 6-8RM resistance increases to 60 kg over

time, it is reasonable to state that person has increased bench press strength by approximately 20%.

Conclusions

Trainees have their own specific direct relationship between 1RM and relative muscular endurance. This relationship may vary among trainees and among different exercises within an individual trainee. For example, a trainee may have a 50 kg 1RM free weight bench press and a 40 kg 8RM. However, that individual also may have a 50 kg 1RM free weight rowing exercise and a 30 kg 8RM. The point is that each trainee's relationship of 1RM and 8RM for those specific exercises remains unaltered with training. If there is a 10% increase in 8RM with training, that trainee's 1RM for that exercise also would have increased approximately 10%.

The first step is to decide – based on a personal preference – a range of repetitions for resistance training. For example, if the selected range is 8-10 repetitions, determine the amount of resistance for eight repetitions in good form at a specific repetition duration such as 3s:3s. This would accomplish several things simultaneously: it determines the resistance and repetition duration for each exercise employed in the resistance training program and establishes a baseline strength level (8RM) for each exercise to evaluate progress (strength gains). There is very little evidence to suggest that any particular range of repetitions, repetition duration, or the amount of resistance for any muscle group will result in a superior specific outcome such as strength gains that is even remotely related to the manipulation of these training variables (90).

The bottom line to stimulate strength gains is to select a load that requires a reasonable effort on the final repetition of the set and gradually increase the resistance (progression) when the trainee exceeds the desired range of repetitions for the specific selected repetition duration [90]. The level of effort required for an optimal stimulus is unknown. When possible, auscultatory blood pressure should be monitored on a regular basis toward the end of a set in special populations such as those trainees with hypertension.

The focus of this review was not to question whether any of the prediction equations are valid for estimating the 1RM. The primary purpose was to challenge whether it is ever necessary to predict or know the actual 1RM for any exercise in order to prescribe the resistance for training or to estimate strength gains. The answer to that question is that the only people in the entire resistance training population who need to know their 1RM for any exercise are competitive powerlifters and weightlifters – and they are aware of their actual 1RM when they practice lifting the heaviest possible resistance for their sport of powerlifting or weightlifting. The exceptions to that answer are the participants in valuable research stud-

ies such as those that directly measured intra-arterial blood pressure [63-68] or those that established the specific individual relationships between 1RM and the maximal repetitions with a submaximal resistance for specific exercises [27, 66, 79-83, 87-89].

The numerous studies that developed 1RM prediction equations [18-25], attempted to validate the equations [26-38], speculated on how many sessions are required to obtain a valid 1RM [39-41], and examined different warm-up protocols [42] raise the interesting unanswered question of why numerous researchers, reviewers, editors and publishers have devoted countless hours to investigate, report, and publish a plethora of studies that have very little valid practical application to resistance training. The preponderance of evidence strongly suggests that neither the 1RM nor the predicted 1RM is required to assess progressive strength gains.

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