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The validity of I-Rm prediction charts for predicting submaximal workloads

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The Validity of 1-RM Prediction Charts for Predicting Submaximal Workloads

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ABSTRACT

THE VALIDITY OF 1-RM PREDICTION CHARTS FOR PREDICTING SUBMAXIMAL WORKLOADS IN EXPERIENCED ADULT WEIGHTLIFTERS

by John M. Gilligan

The accuracy of 1-RM prediction charts for predicting workloads was examined in 20 male and 18 female participants aged 18 to 35 yr. On test day 1, participants were tested for 1-RM values on the bench press and leg press exercises. On test day 2, participants completed repetitions to failure with their predicted 2-RM, 6-RM and 10-RM loads. Statistical analysis revealed that male participants completed significantly more repetitions than predicted on both the leg press and the bench press at all three workloads. Statistical analysis revealed that female participants completed significantly more repetitions than predicted at all three workloads on the leg press and at the 6-RM and 10-RM workloads on the bench press. There was no significant difference at the 2-RM workload on the bench press in females. The data suggest that 1-RM prediction charts predict workloads that are too light to achieve muscular failure at prescribed repetition values.

This thesis is dedicated to Dr. Craig Cisar to whom I will always look up as a professional mentor.

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Chapter 1

INTRODUCTION

The health and fitness field has recently recommended that for optimal health, properly designed resistance training should be added to exercise programs (American College of Sports Medicine, 1990; American Council on Exercise, 1991; Wathen, 1994). One important factor in weight training programs is determining appropriate load assignments in order to achieve maximal gains in strength (Fiatarone et al., 1990; Wathen, 1994). One commonly used method for determining load assignments is by using selected percentages of one-repetition maximum (1-RM) (Sienna, 1989; LeSuer, McCormick, Mayhew, Wasserstein, & Arnold, 1997; Ware, Clemens, Mayhew, & Johnston, 1995; Wathen, 1994). One-repetition maximum refers to the maximum weight that can be lifted with correct form for one repetition during a standard weightlifting exercise (McArdle, Katch & Katch, 1996). When proper 1-RM levels are determined, it is possible to estimate how many repetitions may be completed with load assignments based on selected percentages of 1-RM, or conversely, how much weight will challenge an individual to complete a determined number of repetitions (LeSuer et al., 1997; Wathen, 1994).

The performance of maximal lifts to determine a 1-RM is considered unsafe in many populations such as the elderly, pre-adolescent, and those with a history of heart disease or stroke (McArdle et al., 1996). Furthermore, the use of maximal lifts has been shown to cause musculoskeletal injuries such as ligament sprains and fractures (Pollock et al., 1991; Risser, Risser, & Preston, 1990; Wathen, 1994).

To determine actual 1-RM values, a method of trial and error must be used in which the lifter starts with a load that is close to her/his maximal capacity and subsequently adds weight until only one repetition is completed with good form (McArdle et al., 1996). This value should be achieved in the fewest attempts possible to minimize the effects of fatigue.

The use of prediction equations to estimate 1-RM values has been widely used, but only the Mayhew Equation has been validated statistically to predict 1-RM values for multiple populations (Ware et al., 1995). These equations are cumbersome to use and consistently overestimate 1-RM levels in both upper body and lower body exercise (Ware et al., 1995).

The use of 1-RM values has become the most common and simplest method to predict appropriate submaximal training loads (Mayhew, Ware, & Prinster, 1993) and, therefore, requires a safe method of estimating 1-RM values without the dangers associated with maximal lifts. If accurate 1-RM values can be predicted from submaximal repetitions completed to failure, then subsequent training loads may be accurately predicted as well. This can aid lifters in establishing training loads that are challenging as well as safe. When strength gains are made from training, new 1-RM values can be calculated easily by using prediction charts coupled with the weight lifted and the number of repetitions completed to failure. Based on the new 1-RM, training workloads can then be established.

Statement of the Problem

To receive maximal results from weight training programs, proper loads must be established that challenge weightlifters to complete a set number of repetitions (depending on their goals), yet are safe enough to reduce the risks of injury while training. The National Strength and Conditioning Association (1985), and the American Academy of Pediatrics (1983), have suggested that the 10-RM level be chosen to evaluate the strength of adolescent lifters. Ten-repetition maximum refers to the maximum amount of weight with which the lifter can complete 10 repetitions.

Research needs to be done to determine which methods of estimating RM values are the most efficient and accurate. It may be difficult to use prediction equations in the weight room setting because they are difficult to use and calculators are not readily available. Another problem with these equations is that they only predict 1-RM values from submaximal repetitions. They have no use in predicting other RM values which are more commonly used for load assignments in weight training programs.

Another common method used to estimate RM values is the use of 1-RM prediction charts (Appendix A). These charts are easy to use and typically estimate RM values from 1-RM through 10-RM (Wathen, 1994; Mayhew et al., 1993). This enables submaximal workloads to be predicted from 1-RM values. The problem associated with these charts is that they have not been validated (Morales & Sobonya, 1996). Many 1-RM charts predict that different numbers of repetitions will be performed to failure at selected percentages of a 1-RM. In order for these charts to be properly used, they must be validated by research so trainers and therapists can be confident that they are selecting submaximal workload assignments that sufficiently challenge the lifter to complete the desired number of repetitions.

Purpose of the Study

The purpose of this study was to determine if 1-RM prediction charts are statistically accurate in predicting submaximal workloads at the 2-RM, 6-RM and 10-RM level that will result in momentary muscular failure in experienced adult weightlifters.

Null Hypothesis

There will be no statistically significant difference between the number of repetitions completed to momentary muscular failure at the 2-RM load assignment and that predicted by the 1-RM prediction chart in either the female or male participants. There will be no statistically significant difference between the number of repetitions completed to momentary muscular failure at the 6-RM load assignment and that predicted by the 1-RM prediction chart in either the female or male participants. There will be no statistically significant difference between the number of repetitions completed to momentary muscular failure at the 10-RM load assignment and that predicted by the 1-RM prediction chart in either the male or female participants.

Delimitations

The sample was delimited to participants between the ages of 18-35 years. Participants were delimited to strength trained males and females. Participants were delimited to those with experience in performing the bench press and leg press exercises. Participants were delimited to those in good health and free from any joint injury that would affect performance at the time of testing.

Limitations

The factors in this study which could not be controlled included the following.

1. Lack of maximal effort from participants resulting from their attitudes toward strenuous lifting or inexperience.
2. Weight plates selected were rounded off to the nearest pound (as measured on a balance scale).
3. The dietary and rest habits of participants before and between test days.
4. Daily variations in maximal strength levels.
5. Findings may only apply to multi-joint exercises.
6. Findings may only be specific to the muscle groups primarily used while performing the bench press and leg press.
7. The honesty of participants regarding their weight lifting experience and health.
8. The establishment of 1-RM values may have led to a learning effect toward lifting to momentary muscular failure.

Definition of Terms

Load Assignment The amount of resistance to be used while performing an exercise. Selected percentages of 1-RM are often prescribed for a predetermined number of repetitions (Wathen, 1994).

Momentary Muscular Failure The point at which no more repetitions can be completed with correct form.

One-repetition maximum (1-RM) The maximum amount of weight lifted for one repetition with correct form while performing a weightlifting exercise (McArdle et al., 1996).

Repetition One complete cycle in a series of consecutive movements of a resistance exercise (Sienna, 1989).

Repetition Maximum (RM) The maximum weight load that can be lifted for a specified number of repetitions. If 100 lb is the highest weight load with which a lifter can complete five repetitions, then her/his 5-RM is 100 lb (Wathen, 1994).

Strength The maximal force that a muscle or muscle group can generate at a predetermined velocity (Baechle, 1994).

Operational Definitions

Free of Joint Injury A participant who has not had any unordinary pain or impaired functioning in any joint for the preceding 2 months.

Strength Trained Having lifted consistently at least two times per week for the last 3 months.

Summary

In recent years, it has become common to base weight lifting program load assignments on 1-RM values (LeSuer et al., 1997; Mayhew et al., 1993; Ware et al. 1995). With load assignment (i.e., training intensity) being so essential in optimizing gains (Wathen, 1994), it is important for 1-RM values to be accurately predicted based on submaximal repetitions to failure. Prediction equations have been shown to overestimate 1-RM values (Ware et al., 1995). Therefore, lifters may attempt loads that are either too heavy, or be unable to complete the specified number of repetitions prescribed by their trainer, doctor, or therapist. The use of 1-RM prediction charts is a safe and time efficient way to predict 1-RM levels, but it has not been established as a statistically accurate method. This is why it is important for 1-RM prediction charts to be statistically tested.

Chapter 2

REVIEW OF LITERATURE

Introduction

Weightlifting is an integral part of total fitness for athletes and non-athletes (American College of Sports Medicine, 1990; American Council on Exercise, 1991). The following investigation sought to determine whether 1-RM prediction charts are a valid method for determining 1-RM values as well as submaximal training loads for programs that have a prescribed number of repetitions to be completed in each set. The review of literature is divided into: A) benefits of strength training, B) literature on weightlifting injuries, C) literature on strength testing and RM prediction methods, D) literature regarding load assignments and rest intervals in weightlifting programs, E) summary of the most relevant literature.

Benefits of Strength Training

The practice of weight training has become increasingly popular in recent years (American Council on Exercise, 1991; McArdle et al., 1996; Wathen, 1994). In 1990, the American College of Sports Medicine issued a position paper that added weight training to the list of activities that should be performed to increase levels of lean tissue, as well as prevent deterioration in muscle functioning as one gets older.

The American Council on Exercise (1991) defined strength training as the process of utilizing resistance training with progressively heavier load assignments for the purpose of increasing the strength of the musculoskeletal system. They proceeded to identify some positive adaptations that result from proper weight training programs. The list of benefits included increased muscle fiber size, increased muscle contractile strength, increased tendon tensile strength, increased ligament tensile strength, increased physical capacity (i.e., the ability to perform exercise or work), better perception of one's physical appearance, increased metabolic functioning with a concomitant decrease in body fat percentage, and reduced risk of injury.

The elderly have shown large improvements in strength levels as well as decreases in body fat when participating in resistance training programs (Frontera, Hughes, Lutz, & Evans, 1991). In a study done by Janney (1987), it was concluded that women with higher absolute strength levels in flexion and extension at the elbow and knee joints had higher bone mineral densities than their weaker counterparts. This has important implications for the elderly, particularly women, because of the increased risk of osteoporosis as a function of age. Strength training clearly increases the functioning of individuals regardless of age.

Weightlifting Injuries

Although the benefits of weightlifting are numerous, there will always be a risk for injuries to occur, even in properly designed programs. Injury prevention should be of major concern with any weightlifting program. If done properly, weightlifting will prevent more injuries than it will cause (Wathen, 1994).

The types of injuries occurring during weightlifting can range from minor muscle strains and ligament sprains, to more serious injuries to the spine or even heart failure. In 1985, the NSCA (National Strength and Conditioning Association) released a position paper on prepubescent weight training guidelines. They recommended that prepubescent lifters abstain from 1-RM testing because of the greater risk for injury with maximal loads. It has been recommended that certain populations such as preadolescents, the elderly, cardiac rehabilitation patients, or individuals with hypertension abstain from 1-RM tests because of the associated health risks (McArdle et al., 1996). It has been hypothesized that the use of maximal loads with prepubescent participants may lead to epiphyseal damage in the long bones, leading to impaired growth patterns (Bilcheck, 1989). People within these populations should perform strength tests that can predict 1-RM values from submaximal repetitions to failure. This can be accomplished safely by using either 1-RM prediction equations or prediction charts.

Mayhew et al. (1993) reported that the use of 1-RM testing may be limited by the use of unaccustomed heavy loads and fear of failure. They also reported that the use of 1-RM testing has the potential for damage to bone growth plates which may lead to undesirable growth patterns in adolescent weightlifters. They stressed the importance of having a safe and reliable method for predicting maximum strength from submaximal repetitions completed to failure.

The practice of weightlifting among the elderly has become increasingly popular in recent years. In a study using 1-RM lifts on 10 Nautilus™ selectorized machines in men and women between the ages of 70-79 years, 11 of the 57 participants reported having injuries to either the knee, arm, back, or shoulder (Pollock et al., 1991).

Measuring the injury rates occurring during 1-RM testing is difficult because university human subjects committees are unlikely to approve research where it is hypothesized that participants are likely to be injured. There is research available, however, that indicates that the likelihood of injury is increased when using heavy load assignments (Madsen & McLaughlin, 1984; Mazur, Yetman, & Risser, 1993).

Strength and Repetition Maximum Testing

The most simple and popular method for determining strength is using a 1-RM test (Mayhew et al., 1993). Experienced and novice weight trainers often use the 1-RM to assess strength levels and construct programs that will result in continued progress (LeSuer et al., 1997). Despite its ease of use and inherent accuracy in assessing strength levels, there are many drawbacks to 1-RM testing such as the risk for injury and the undesirability of lifting maximal loads. LeSuer et al. (1997) noted that the use of 1-RM testing can be of concern to weight training instructors and practicing lifters because of the time needed to prepare for and perform the 1-RM and the injury risks associated with handling heavy weights. A simple, safe, and accurate procedure for estimating the 1-RM was recommended for strength and conditioning specialists, sports medicine physicians, athletic trainers, and weight trainers who wish to design challenging and safe resistance training programs.

A commonly used technique for 1-RM testing (Braith, Graves, Leggett & Pollock 1993; Hoeger, Hopkins, Barette, & Hale, 1990; Invergo, Ball, & Looney, 1991; Ware et al., 1995) is to have participants perform multiple warm up sets with a light weight of their choice. The initial test load is then based on the subjective experience of the lifters and the loads with which they have previously been challenged. If the participant completes the lift, then additional weight is added as determined by the participant for the next lift. This process is repeated until the lifter reaches a workload with which one repetition can not be completed. In most cases, the 1-RM is achieved within 3-5 lifts. The reliability of this technique has been reported to be high ($r > .93$) (Ware et al., 1995).

Mayhew et al. (1993) identified four steps typically taken during the testing process of maximum strength (i.e., 1-RM). The four steps are:

1) warming up thoroughly with light weight loads, stretching, and calisthenics;
2) selecting a weight that the lifter feels will result in failure somewhere between 8-20 repetitions;
3) performing repetitions slowly and in a continuous fashion with no more than 2 s between repetitions; and
4) consulting a table that estimates 1-RM values from submaximal repetitions.

An important consideration when administering 1-RM tests is the effect of external and psychological variables (deVries, 1986). The use of unaccustomed heavy loads and the fear of failure may adversely affect performance (Mayhew et al., 1993). In a study examining the effect of various motivational techniques on muscular endurance performance in the forearm flexor muscles, Nelson (1978) found that participants given goals ranging from realistic to unrealistically high outperformed a control group that was given no instruction. The group that was given the highest goals significantly outperformed the other participants. This indicates that the setting of challenging goals may contribute to motivating participants to give their best effort.

Most of the research on 1-RM prediction has focused on prediction equations. Some of the most common equations are listed below.

Mayhew Equation-- %1-RM= $52.2+41.9e^{-.055reps}$ (Mayhew, Ball, Arnold & Bowen, 1992)

Lander Equation-- %1-RM= 101.3-2.67123*reps (Lander, 1985)

Brzycki Equation-- %1-RM= 102.78-2.78*reps (Brzycki, 1993)

Epley Equation-- 1-RM= (0.033* rep weight)*reps + rep weight (LeSuer et al., 1997)

Lombardi-- 1-RM=rep weight*$(reps)^{.1}$ (LeSuer et al., 1997)

O'Connor-- 1-RM=rep weight* (1+.025*reps) (LeSuer et al., 1997)

Wathen-- 1-RM=100*rep weight/(48.8+ 53.8*$e^{-.0758reps}$) (LeSuer et al., 1997)

(Asterisks indicate multiplication)

Ware et al. (1995) investigated the accuracy of estimating 1-RM bench press and squat strength in college football players using muscular endurance performance. The purpose of the study was to determine if maximal strength can be accurately predicted by using submaximal repetitions to failure on the bench press and squat exercises. The participants were 45 NCAA Division II football players who had undergone a 12 week off-season conditioning program. Participants selected weights that they felt would be approximately 70% of their 1-RM for each lift, and completed as many repetitions to failure as possible.

The results indicated that the participants selected weights that averaged 71.3% of 1-RM on the bench press and 68% of 1-RM on the squat. The participants completed an average of 13.9 repetitions on the bench press and 17.4 repetitions on the squat. The results indicated that the Epley, Brzycki, and Lander equations significantly overestimated bench press 1-RM values, and the Mayhew equation significantly underestimated it. All four of the equations significantly overestimated the squat 1-RM values.

The mean bench press value for the participants was 124.3 kg. The Brzycki equation calculated a predicted mean of 139.8 kg, the Epley equation predicted a mean of 129.1 kg, the Lander equation predicted a mean of 138.4 kg, and the Mayhew et al. equation predicted a mean of 121.2 kg. In the squat exercise, the mean for participants was 179.2 kg. The Brzycki equation predicted a mean of 227.1 kg, the Epley equation predicted a mean of 190.9 kg, the Lander equation predicted a mean of 224.9 kg, and the Mayhew et al. equation predicted a mean of 227.7 kg.

The Mayhew et al. equation predicted 1-RM values that ranged from 41.9 kg lower than actual 1-RM to 7.3 kg above actual 1-RM. The Epley equation predicted 1-RM values ranging from 33.1 kg lower than actual 1-RM to 19.9 kg higher than actual 1-RM. The Brzycki equation predicted 1-RM values ranging from 17.6 kg below actual 1-RM to 49.6 kg above actual 1-RM. The Lander equation predicted 1-RM values ranging from

18.4 kg below actual 1-RM to 47.4 kg above actual 1-RM. Clearly, the prediction equations were not an accurate means of predicting 1-RM values, particularly for the squat exercise.

The results of the Ware et al. (1995) study seemed to indicate that prediction equations were less accurate in predicting 1-RM for lower body exercises. Performing 17.4 repetitions to failure with 68% of 1-RM was higher than any of the prediction equation estimations.

The findings of Ware et al. (1995) are similar to those of Hoeger et al. (1990) who found that participants completed 1.6 times as many repetitions in the leg press as in the bench press using 80% of 1-RM, and 1.7 times as many repetitions in the leg press as in the bench press using 60% of 1-RM. Ninety-one participants (plus data from 38 subjects from previous research) were tested to determine the number of repetitions they could complete with 80% of 1-RM, 60% of 1-RM, and 40% of 1-RM on seven separate weight training exercises.

They found a significant difference between trained and untrained males in the number of repetitions completed at selected percentages of 1-RM in five of the seven exercises, including the leg curl, lat pulldown, knee extensions, arm curl, and sit-ups at all three percentages of 1-RM. The two exercises that they found no significant differences in were the bench press and leg press exercises. Therefore, the bench press and leg press exercises may be the most accurate exercises for predicting maximal strength in participants.

Among female participants, there was a significant difference between trained and untrained participants in the number of repetitions completed at all three percentages of one-repetition maximum on all seven exercises. The findings indicated that using selected percentages of 1-RM values did not always produce the same number of repetitions completed across different lifts.

LeSuer et al. (1997) investigated the accuracy of seven prediction equations (listed on page 13) for predicting 1-RM values in the bench press, deadlift, and squat exercises in 67 untrained college students (40 males and 27 females) based on submaximal repetitions to exhaustion. Despite having high correlation coefficients ($r > 0.95$) for all three exercises, the differences between predicted repetitions and completed repetitions were significantly different from zero in five of the seven equations in the bench press exercise. All seven of the equations significantly underestimated the deadlift 1-RM values, while six out of seven equations significantly underestimated the squat 1-RM values. Only the Wathen equation was accurate for predicting squat 1-RM values (predicted mean of 203.4 lb compared to an actual mean of 208.0 lb). Both the Wathen equation (136.1 lb predicted mean) and the Mayhew equation (136.2 predicted mean) were accurate predictors of bench press strength ($\underline{M}$ = 137.3 lb).

The findings in this investigation were in agreement with those of Prinster, Mayhew, Arabas, Ware and Bemben (1993) in determining that the Mayhew and Wathen equations were better predictors of bench press 1-RM values. These equations tended to underestimate bench press 1-RM by only 1-5 lb in most participants.

Slovak (1996) compared actual and predicted 1-RM by repetitions to failure with 225 pounds on the bench press exercise in NCAA Division II football players. Participants performed an actual 1-RM test, and a test to see how many repetitions to failure they could complete with 225 lb. One-repetition maximum predictions were made using the Epley, Mayhew, and Brzycki equations based on repetitions with the 225 pound load. The results indicated that 1-RM values can be accurately determined by entering the number of repetitions completed with 225 lb on the bench press test into the Mayhew and Epley 1-RM prediction equations. The Brzycki equation underestimated 1-RM bench press values significantly. The results of using the 225 lb bench press test in college football players may not be indicative of how other populations would perform due to possible inexperience in lifting or inability to lift heavier weight loads.

In 1995, Mayhew et al. used six prediction equations to estimate 1-RM bench press values in male participants of varying training levels and age (college athletes, untrained students, trained students, and trained middle-aged men). Participants completed a 1-RM test, and then 4-10 days later selected a submaximal load with which to complete as many repetitions as possible.

In participants who selected loads of 10-RM or heavier, the results showed that three equations significantly overestimated 1-RM values and two significantly underestimated them. Only the Brzycki equation was determined to be accurate for predicting 1-RM values. The Epley, Lander, Lombardi, Mayhew et al., and Wathen equations all predicted significantly different 1-RM values than actual figures. In participants who selected loads lighter than 10-RM, all six equations predicted significantly different 1-RM values.

In general, prediction equations tend to be more accurate in estimating 1-RM values when using fewer repetitions to failure. LeSuer et al. (1997) found that using less than 10 repetitions to failure was more accurate in estimating 1-RM levels in the bench press, parallel squat, and deadlift exercises. Ware et al. (1995) concluded that using higher repetitions to failure is not an accurate means of predicting maximum strength levels (1-RM) in the squat or bench press exercises among experienced weightlifters. They found that prediction equations inaccurately predicted 1-RM values by as much as 48.5 kg in the squat and 14.7 kg in the bench press.

Stone and O'Bryant (1987) concluded that using heavier loads is more advisable when predicting 1-RM from submaximal repetitions. Their conclusions were supported by Ware et al. (1995). To get the most accurate results, Brzycki (1993) recommended using 10-RM levels or heavier when using his formula.

Madlena (1996) investigated the relationship between ratings of perceived exertion (RPE) and repetitions to exhaustion with various percentages of 1-RM. The findings indicated that there was a significant difference in repetitions completed to exhaustion on different exercises. RPE values were also significantly different at the same percentages of 1-RM for the various lifts. Participants completed more repetitions on the chest press and the lat-pulldown exercises than the arm curl and leg extension machines. Participants reported lower RPE values on the lat-pulldown exercise than the arm curl and leg extension exercises. These findings indicate that RPE levels may be lower in multiple-joint exercises than single-joint exercises. Participants completed more repetitions on multiple-joint exercises as well.

The use of 1-RM prediction charts is controversial because their accuracy for different lifts and experience levels seems to be inconsistent. The charts seem to be more accurate for multiple-joint free weight exercises, and less accurate for machine exercises (Hatfield, 1985).

One problem with present 1-RM prediction charts is that they tend to have linear 1-RM prediction curves. The 1-RM prediction chart by Wathen (1994) predicts that one additional repetition will be completed with each 2.5% decrease in load assignment (based on 1-RM). This indicates that a participant with a 1-RM of 300 pounds would only be able to perform 30 repetitions with a load of 82.5 pounds. It seems that at some point, the linear prediction trend would have to become exponential or curvilinear.

The use of female participants for 1-RM prediction testing is rare. One study, however, investigated the use of the YMCA bench press test and the modified YMCA bench press test to determine 1-RM levels in 84 previously untrained women ranging from 18-25 years of age (Rose & Ball, 1992). The YMCA bench press test measures how many repetitions to failure can be completed with 25 lb. The modified YMCA bench press test measures repetitions to failure with 45 lb. The results indicated that using relative muscular endurance combined with body weight was more accurate (SEE=3.27 kg, r^2=.66) than using muscular endurance alone (SEE=3.34, r^2 =.62) when predicting 1-RM values. They concluded that using the YMCA bench press test and/or the modified YMCA bench press test combined with body weight is a safe and time-efficient method for determining 1-RM values for untrained women lifters.

Some research indicates that the prediction of maximum strength based on submaximal repetitions completed to failure may be inaccurate in experienced lifters. Braith et al. (1993) concluded that the relationship between muscular endurance and muscular strength may be altered by heavy-resistance weightlifting programs, and the use of prediction equations may not be prudent.

Morales and Sobonya (1996) examined the effectiveness of 1-RM prediction charts by having 23 college athletes perform 1-RM tests in the bench press, squat, and power clean lifts. The participants also performed sets with 70%, 75%, 80%, 85%, 90%, and 95% of their 1-RM. The results indicated that the best predictor for 1-RM on the bench press exercise was a load of 95% of 1-RM (2-RM value from prediction chart); the most accurate predictor of 1-RM in the squat exercise was 80% of 1-RM (8-RM value from prediction chart), and the best indicator for the power clean exercise was 90% of 1-RM (4-RM value from the prediction chart). These results indicated that the most accurate submaximal load for predicting a 1-RM value varies depending upon the exercise.

Morales and Sobonya (1996) concluded that the mean number of repetitions completed at selected percentages of 1-RM did not significantly differ from those predicted by the one-repetition maximum prediction chart. The number of repetitions completed at all percentages of 1-RM did not differ significantly between the three lifts. This is in accordance with Fleck and Kraemer (1987) who concluded that 1-RM prediction charts are more accurate in predicting 1-RM for multiple joint exercises that recruit large muscle groups than single-joint exercises that recruit small muscle groups.

Load Assignments and Rest Intervals

It has been shown that training intensity is the most important variable involved in making progress towards set goals (Fleck & Kraemer, 1987; Pauletto, 1986). For many athletes and weightlifters, load assignment (i.e., intensity) is determined by using a prediction chart in conjunction with a 1-RM test (Wathen, 1994). Often lifters (particularly beginning lifters) are increasing 1-RM levels on a consistent basis and need an easy way to determine their new 1-RM (Wathen, 1994). This is necessary because many training programs base load assignments on a percentage of 1-RM, and to continue overloading your muscles, an accurate 1-RM must be readily calculated.

Load assignments for weightlifters will vary depending on their goals and previous training experience. Research has shown that beginning lifters can make strength gains utilizing loads as low as 35% of their 1-RM in isometric exercises and 45% of 1-RM in circuit training programs (Fleck & Kraemer, 1987). Other research has indicated that experienced lifters wishing to increase strength levels need to use loads of at least 80% of 1-RM (Hatfield, 1985; Simmons, 1988). Some researchers report that in order to make maximal gains, lifters must attempt a set with maximal effort once per week, while utilizing lower intensities during the remainder of the week (Fleck & Kraemer, 1987).

However, performing 1-RM training is more effective when done only once per week (Wathen, 1994).

Fleck and Kraemer (1987) reported that the majority of research available indicated that using RMs of six or fewer led to greater strength and power improvements. RM loads of 6-12 provided moderate gains in endurance, power and strength, and RMs of 20 and above provided greater stimulus for muscular endurance improvement. It has been shown that participants who engage in high intensity training (heavier loads) had greater hypertrophy of fast-twitch muscle fibers (Type II fibers), and those using lower intensity (lighter loads) elicited greater hypertrophy in slow-twitch muscle fibers (Type I fibers). Those wishing to elicit hypertrophy in both fast-twitch and slow-twitch fibers should employ a program consisting of both high intensity and low intensity load assignments (Tesch & Larson, 1982).

Load assignment is also an important variable in programs designed for all types of rehabilitation. In recent years, physicians placing cardiac rehabilitation patients on circuit training resistance programs have found positive results (Sparling & Cantwell, 1989). These programs have prescribed resistance training at intensities of 40-60% of 1-RM. It has been found that cardiac patients can perform 1-RM testing with fewer symptoms than a graded-exercise test, provided that they avoid using a Valsalva maneuver (Wathen, 1994).

When working with athletes or clients who have been injured for extended periods of time, the fitness professional must take into account the effects of detraining, including losses in strength, endurance, power, and flexibility. It has been recommended to start with loads of approximately 50-60% of 1-RM and slowly increase the resistance, providing there is no accompanying pain or inflammation (Wathen, 1994).

When designing 1-RM tests or weight training programs, rest interval length must be considered. In order to make appropriate gains from a program, adequate rest periods between sets must be observed (Ballor, Becque, Marks, Nau & Katch, 1989). When performing 1-RM testing, load assignments are similar to those used in programs designed for strength enhancement. Therefore, rest intervals between attempts should be similar (Weiss, 1991). In a study by Weir, Wagner, and Housh (1994), participants were tested on repeated maximal bench press efforts with rest intervals of either 1, 3, 5, or 10 minutes. Statistical analysis found no significant differences in performance between the varying rest interval lengths. This indicates that the ability to perform maximal bench presses is not compromised so long as rest interval lengths are at least 1 minute.

Although Weir et al. (1994) concluded that 1 minute rest intervals are sufficient, the majority of research indicates that rest intervals of approximately 3-5 minutes are advisable between heavy sets of exercise (Fleck & Kraemer, 1987; McArdle et al., 1996; Weiss, 1991). Pincivero, Lephart, and Karunakara (1997) examined the effects of rest interval length on strength gains in participants who trained on isokinetic machines for 4 weeks. Participants were tested for maximal knee extension and knee flexion strength at 60°/second (5 repetitions per set) and 180°/second (30 repetitions per set), and functional strength (single leg hop for distance). One group rested 40 seconds between sets during the 4 week training period, while the second group rested 160 seconds between sets. The results indicated that participants who rested longer between sets (160 seconds) made greater improvements in strength as a result of a more complete recovery between sets.

Jaskolski and Jaskolska (1988) examined the effects of maximal exercise on phosphagen depletion. Seven oarsmen performed the Margaria-Kalamen anaerobic power test on a Medicor cycloergometer. The results indicated that a 5 minute recovery after maximal anaerobic effort was sufficient for phosphagen regeneration.

High intensity weight training utilizing heavy loads lifted for short periods of time will be fueled primarily by stored phosphagens (ATP and PC) within the working muscles. When performing all-out activity, these phosphagen stores may be depleted in as fast as 10-15 seconds (Wathen, 1994). In order to replenish these stores, inactive rest intervals of about 2.5-3 minutes are required (Tesch & Larson, 1982).

The literature on rest days between workout sessions is inconclusive. Early research showed that when beginning a weight training program, a 3 day a week schedule with alternate days off (48 hours rest between workouts) would yield the greatest gains in strength (Berger, 1972). Experienced lifters who train for strength or power, and/or use maximum or near maximum resistance, require longer rest intervals ranging from 2-5 days between similar workouts (Fleck & Kraemer, 1987; Stone & O'Bryant, 1987). Some research indicates that alternating heavy resistance sessions with lighter sessions will enable faster recovery and better long term results (McArdle et al., 1996; Wathen, 1994).

Sewall and Lander (1991) examined the effect of rest periods between subsequent determinations of 1-RM strength in the bench press and squat exercises. Thirty male participants were separated into three categories. One group rested 2 hours between 1-RM determinations, the second group rested six hours, and the third rested 24 hours. The data showed no significant differences between the three groups in their ability to repeat their previous 1-RM performance. Although these rest intervals may be too short between complete workouts, perhaps they are sufficient due to the lower volume of work performed during a 1-RM test compared to a complete training session consisting of multiple sets on multiple exercises.

When performing any form of weight training or 1-RM test, a proper warm-up should be performed. Research shows that properly warming up muscles before lifting weights increases muscle contraction force capabilities and optimizes muscle elasticity (Fleck & Kraemer, 1987). Generally, fitness experts recommend that enough warm-up sets be performed to raise the core temperature of the working muscles as well as mentally prepare the lifter to focus on the lift (Wathen, 1994).

Wathen (1994) recommends that warm-up activities be performed with approximately 50%-70% of the load to be utilized during training or testing. He noted that a warm-up is necessary for a safe and accurate determination of a 1-RM value.

Summary

Resistance training has been identified as an important factor in optimizing lifelong fitness and maintaining lean tissue (American College of Sports Medicine, 1990). A major component contributing to the success of resistance training programs is intensity (Wathen, 1994). Intensity (i.e., load assignment) is most commonly referred to as a percentage of the lifter's 1-RM (Ware et al., 1995).

In order for 1-RM to be used as a basis for training program load assignments, an accurate and easy means of calculation is necessary (LeSuer et al., 1997). The performance of maximal lifts may lead to injury (McArdle et al., 1996); therefore, determining 1-RM levels from submaximal repetitions is advisable (American Academy of Pediatrics, 1983; National Strength and Conditioning Association, 1985). The most commonly used methods for predicting 1-RM levels are 1-RM prediction charts and 1-RM prediction equations (Mayhew et al., 1993). The problem with 1-RM prediction equations is that they consistently yield inaccurate 1-RM levels (Ware et al., 1995), and can't be used to predict submaximal RM values. The accuracy of 1-RM prediction charts is controversial (Hatfield, 1985) and has not been deemed valid by statistical procedures.

Because of the usefulness of calculating 1-RM values for submaximal workload assignments or for physical fitness testing, an accurate 1-RM prediction chart must be formulated that enables the repeated calculation of 1-RM values without using actual 1-RM testing. Those lifting weights will find that their strength level may increase on a weekly basis, particularly in the early weeks of a strength training program. A valid 1-RM prediction chart can be a useful tool for those who are prescribing submaximal workloads for athletes or non-athletes.

Morales and Sobonya (1996) noted that the accuracy of 1-RM prediction charts has not been established. If the charts can be validated to accurately predict 1-RM values, then correct workload prescription can be more easily accomplished by strength and conditioning professionals. Accurate workload prescription will enhance the strength and power gains made by athletes using resistance training. They concluded that the discrepancy in the literature examining the use of 1-RM prediction remains unresolved because no one has measured the predictive power of submaximal repetition tests.

In order to prescribe workloads for clients and athletes, fitness professionals need an accurate means of calculating submaximal RM values that will result in momentary muscular failure close to the prescribed number of repetitions. This would enable clients and athletes to make optimum gains towards their goals.

Chapter 3

METHODOLOGY

Introduction

This investigation focused on determining the validity of 1-RM prediction charts in estimating submaximal RM values based on established 1-RM values. The methodology is subdivided into participants, instrumentation, research design, and statistical analysis.

Participants

A total of 38 participants (20 male and 18 female) between the ages of 18-35 years were tested for 1-RM values in the bench press and leg press exercises. Subsequently, participants were tested approximately 48-72 hours later to determine how many repetitions they could complete to failure with their predicted 2-RM, 6-RM, and 10-RM load assignments based on their established 1-RM. The recruitment of participants was done through weight training classes at San Jose State University in San Jose, CA, and members at Reach Fitness Club in Los Altos, CA. Participants consisted of weightlifters who had experience in performing the bench press and leg press exercises. Strength-trained participants were used because individuals that refer to 1-RM prediction charts are likely to be experienced lifters on programs designed by fitness professionals. Using strength-trained participants may help minimize the learning effect that might take place after numerous sets to failure with heavy loads.

Participants completed an informed consent (see Appendix B) explaining the purpose of the study, associated risks and benefits, their rights as subjects, and an estimate of how much time would be involved in testing. Participants were offered complimentary fitness consulting/programming in exchange for their time and best effort.

Participants filled out a medical questionnaire (see Appendix C) that screened for any potential health risks associated with weightlifting or maximal strength testing. The questionnaire covered health problems including musculoskeletal injuries, diagnosed diseases or illnesses, history of stroke, and past problems with heart disease or heart failure. Participants had their blood pressure (BP) measured. Participants with a BP above 140 mmHg systolic, or 90 mmHg diastolic were ineligible to participate in the study. Participants were asked about their previous weight training experience including how often they trained, how consistently they trained over the preceding 3 months, and experience they had with the bench press and leg press exercises.

Instrumentation

1. Bench press was performed on a standard flat bench.

2. A wooden box or weight plates were provided on which participants could place their feet to prevent lifting their lower back off the bench.

3. Leg press was performed on a 45° sled with free weight plates mounted.

4. Standard Olympic-sized weightplates were used ranging from 2.5-100 pounds. Weight plates were weighed on a balance scale to ensure that proper load assignments were being utilized. Collars ranging from 1.0-5.5 lb were used to ensure accurate weight

loads within 1 lb of the desired load.

5. A piece of white tape was used on the leg press sled to determine the mark at which each participant lowered the weight sled to 90° of knee flexion.

6. Safety spring collars were used during bench press testing as a safety precaution.

7. Two spotters were employed during both the bench press and leg press exercises.

8. Tape markers were placed on the free weight bar to ensure that participants used the same width hand grip on each attempt.

9. Tape markers were placed on the leg press foot platform to ensure that the feet were in the same place on each lift. Feet were placed parallel to each other, shoulder width apart (measured from acromian process to acromian process).

10. A blood pressure cuff and sphygmomanometer were used to determine the participant's resting BP.

11. A stopwatch was used to time rest intervals between sets.

12. A measuring tape was used to measure participant's grip width on the bench press, and shoulder width for foot placement on the leg press.

Research Design

Introduction

Participants were trained on proper lifting techniques and form. A page outlining possible disqualification factors (see Appendix D) was given to participants prior to testing. Participants were tested on the first day to determine their 1-RM values in both the leg press and bench press exercises. A second day of testing (48-72 hours after 1-RM testing) determined how many repetitions participants could complete to failure with their predicted 2-RM, 6-RM and 10-RM levels based on their 1-RM values from day 1. Both testing sessions took place at the same time of day in order to minimize variability due to circadian rhythms.

Practice 1-RM test sessions were conducted with personal training clients at Reach Fitness Club before data collection to minimize unexpected problems that might arise during the testing sessions, thus limiting the effect of external variables on the data collection process. Participants were asked to abstain from any weightlifting or strenuous activity for 48 hours prior to both test sessions.

Testing Day 1

Participants filled out an informed consent form (see Appendix B) outlining the risks and benefits associated with maximum strength testing. Participants completed a medical history/training questionnaire to minimize risks associated with strength testing. Participants had their resting blood pressure (BP) determined to eliminate those with hypertension; participants with BP over 140 mmHg systolic and/or 90 mmHg diastolic were ineligible to participate in the study.

Participants were shown proper form on exercises and briefed on possible factors that would disqualify lifts (see Appendix D). Participants performed two or more warm-up sets with a light load of their choice approximating 50% of their expected 1-RM on both the bench press and leg press exercises. Based on their previous training experience, an initial workload was then determined that approximated 90% of their subjectively determined 1-RM. If the participant successfully completed one repetition, the weight was increased as determined by the participant's feelings from the previous lift. This process was repeated until a load was determined that the participant couldn't successfully lift. The highest figure successfully lifted was recorded as the participant's 1-RM.

Participants performed both the bench press and leg press exercises on the same day. A minimum of a 5 minute rest interval was employed between successive attempts to ensure proper recovery of the stored adenosine triphosphate (ATP) and phosphocreatine (PC) in the working muscles. Participants rested a minimum of 10 minutes between the bench press and leg press exercises. The order in which the participants performed 1-RM testing on the leg press and bench press was randomized to minimize the effects of fatigue. This technique has been employed by Ware et al. (1995), Braith et al. (1993), Hoeger et al. (1990) and Invergo et al. (1991) with high degrees of reliability ($r > .93$).

Testing Day 2

Participants repeated the same warm-up procedures outlined for test day 1. Participants were briefed again regarding proper lifting form. Participants completed as many repetitions to failure as possible with their predicted 2-RM, 6-RM, and 10-RM load assignments. These figures were derived from their previously determined 1-RM (from test day 1) and the RM prediction chart (see Appendix A). Participants performed the 2-

RM load first, the 6-RM load second, and the 10-RM load third because higher repetition loads (i.e., longer duration exercise) are more likely to deplete ATP stores or elevate blood lactic acid, thus requiring longer recovery between sets (McArdle et al., 1996).

Participants performed both exercises on the second test day. Participants alternated between the bench press and leg press to maximize recovery time between sets on the same exercise. A minimum of a 5 minute rest interval was employed between RM test sets on the same exercise, including time spent testing on the other exercise.

Protocol for Correct Exercise Form

Bench Press

The bar was slowly lowered to the chest and touched between the xiphoid process of the sternum and the clavicles. A piece of tape was placed at the proper location for the bar to touch. Participants hesitated briefly and when cued, returned the bar to full elbow extension. Participants were not allowed to hesitate between repetitions. Bouncing of the bar off the chest was not permitted. Elbow wraps were not permitted during testing.

A tape marker was used to ensure that participants used the same hand grip width on each lift, and that the participants' hands were evenly spaced from the midpoint of the bar. The width ranged between 20-30 cm wider than the measured length from the left acromian process to the right acromian process.

Participants were required to keep their feet in contact with the floor or wooden platform (as needed) throughout the entire movement. The participant's lower back remained in contact with the bench throughout the entire movement. Any repetitions that did not meet these criteria were disallowed. If any lift was disqualified, a five minute rest interval was employed, and the lift was attempted again

A spotter was provided to help the participant lift the bar off the rack. This enabled the lifter to save energy for the lift, as well as prevent the bar from coming in contact with the rack during the course of the lift. The spotter was necessary to ensure the safety of participants when a lift was not completed.

Leg Press

The sled was slowly lowered to the point of 90° knee flexion. Participants hesitated briefly and then returned the sled to full knee extension. A tape marker was placed on the sled to mark the point where 90° of knee flexion was reached. Tape markers were placed on the foot platform to ensure that feet were equidistant from each other on each test phase. Feet were placed shoulder width apart (distance from the left acromian process to the right acromian process). Knee wraps were not permitted during testing. The back rest was positioned so participants could lower the sled to 90° of knee flexion without their thighs pressing against their thorax or abdominal regions.

Participants were not allowed to hesitate between repetitions. Bouncing movements at the bottom of the movement were not permitted, and the participant's lower back and ischial tuberosities were required to remain in contact with the support bench throughout the entire movement. Any repetitions that did not meet these criteria were disallowed. If any lift was disqualified, a 5 minute rest interval was employed, and the lift was attempted again. There were no participants disqualified as a result of poor lifting form. One female participant did not show up for the second testing session . A spotter was placed at both sides of the sled to assist the participant when momentary muscular failure was reached.

Instructions for Testing

Participants were instructed to breathe throughout the entire movement. Participants were instructed to give their maximum effort on all phases of testing. Participants were instructed to inform tester(s) if they felt any pain or discomfort before, during, or after the testing phases. All repetitions were performed in a slow and controlled manner. A minimum 3 second count on the eccentric phase was employed. The concentric phase was not timed as participants were required to hesitate until cued between the eccentric and concentric phases of the lift.

Statistical Analysis

Independent t-tests were used for gender comparison of the actual number of repetitions completed to those predicted by the 1-RM Prediction Chart on bench press and leg press. One-sample t-tests were used to compare performance in repetitions completed at each workload on leg press and bench press to the predicted values of 2, 6 and 10 repetitions from the 1-RM Prediction Chart.

Two-way analyses of variance were used to compare the number of repetitions completed for bench press versus leg press in males and females using the 2-RM, 6-RM and 10-RM predicted workloads. Two-way analyses of variance were used to compare the differences in the number of repetitions completed in both the leg press and bench press between actual and predicted at the 2-RM, 6-RM and 10-RM workloads. This was used to determine if the difference between actual repetitions completed and predicted repetitions followed a consistent trend.

Dependent t-tests, one-way analysis of variance, and/or Tukey post hoc analyses were used to further analyze the significant main effects found in the two-way analyses of variance.

Summary

A total of 38 participants (20 males and 18 females) were tested to determine the accuracy of 1-RM prediction charts. Participants filled out an informed consent form as well as a medical history/training questionnaire. Participants were tested on two separate days (48-72 hours between test sessions). The first day consisted of a 1-RM evaluation on the bench press and leg press exercises. The second test day participants performed as many repetitions to failure as possible with their 2-RM, 6-RM, and 10-RM predicted values from the 1-RM prediction charts. Testing was done on 45° leg press sled and a flat bench press, using a standardized protocol in which participants were briefed on proper form.

The submaximal loads of 2-RM, 6-RM, and 10-RM were chosen because they fall within the recommended repetition ranges for increasing strength and power (2-3 repetitions), basic strength (4-6 repetitions) and hypertrophy (8-12 repetitions) (National Strength and Conditioning Association, 1993). Because they fall within these repetition ranges, programs for most athletes are typically designed using loads similar to 2-RM, 6-RM, and/or 10-RM depending on the specific goals.

Statistical procedures consisted of two-way ANOVAs for gender and lift comparisons, independent t-tests and one sample t-tests to determine if the number of repetitions completed with predicted submaximal loads (10-RM, 6-RM, and 2-RM) can be accurately determined from a 1-RM determination. Dependent t-tests, one-way analyses of variance, and/or Tukey post hoc analyses were used to determine significant differences from the two-way analyses of variance.

Chapter 4

RESULTS and DISCUSSION

Results

The purpose of this study was to determine if 1-RM prediction charts are valid for determining submaximal weight loads in experienced lifters between the ages of 18-35 years. The results and discussion of findings are included within this chapter.

A total of 20 males and 18 females participated in this study. On test day 1, participants performed 1-RM tests for the leg press and bench press exercises. On test day 2, participants completed as many repetitions to failure with their predicted 2-RM, 6-RM and 10-RM workloads for the leg press and bench press exercises, based on the 1-RM prediction chart (Wathen, 1994).

The means and standard deviations for the total group (n=38), and the means and standard error of measurement by gender for age, bench press 1-RM, leg press 1-RM, and repetitions completed with the 2-RM, 6-RM and 10-RM loads are summarized in Table1. Table 2 summarizes one-sample t-tests comparing actual number of repetitions completed with the 2-RM, 6-RM and 10-RM workloads to the number of repetitions to failure predicted by the 1-RM prediction chart (Wathen, 1994).

Table 3 summarizes the two-way analysis of variance comparing the number of repetitions completed for the bench press and leg press in females and males, using the 2-RM workload. Table 4 summarizes the two-way analysis of variance comparing the number of repetitions completed for the bench press and leg press in females and males, using the 6-RM workload. Table 5 summarizes the two-way analysis of variance comparing the number of repetitions completed for the bench press and leg press in females and males, using the 10-RM workload.

Table 6 summarizes the two-way analysis of variance for the bench press exercise comparing the differences in the number of repetitions completed and the predicted number of repetitions for the 2-RM, 6-RM and 10-RM workloads in females and males. Table 7 summarizes the two-way analysis of variance for the leg press exercise comparing the differences in the number of repetitions completed and the predicted number of repetitions for the 2-RM, 6-RM and 10-RM workloads in females and males.

Table 8 illustrates the differences between actual and predicted 1-RM values for the leg press and bench press exercises. Actual figures are from data collection on test day 1. Predicted figures are calculated from the mean number of repetitions completed to failure on test day 2 with the participants' predicted 2-RM, 6-RM and 10-RM workloads.

Table 1

Comparison of Genders for Age, 1-RM Values, and Repetitions Completed With 2-RM, 6-RM, and 10-RM Loads

Variable	Overall Group (n=38) (M ± SD)	Females (n=18) (M ± SEM)	Males (n=20) (M ± SEM)	t-value	p
Age (yr.)	24.03 ± 4.86	21.61 ± .93	26.20 ± 1.04	-3.27	.002
BP 1-RM	149.95 ± 80.25	77.33 ± 3.31	214.35 ± 12.26	-10.29	.000
BP 2-RML	3.18 ± 1.86	3.06 ± .53	3.30 ± .33	-.40	.691
BP 6-RML	7.89 ± 2.65	7.89 ± .75	7.90 ± .48	-.01	.990
BP 10-RML	11.45 ± 2.23	11.50 ± .63	11.40 ± .41	.14	.892
LP 1-RM	540.87 ± 174.95	398.72 ± 14.70	668.80 ± 31.16	-7.56	.000
LP 2-RML	4.71 ± 3.11	4.56 ± .72	4.85 ± .72	-.29	.775
LP 6-RML	10.00 ± 3.28	9.72 ± .66	10.25 ± .83	-.49	.627
LP 10-RML	16.08 ± 4.34	15.44 ± .83	16.65 ± 1.12	-.85	.400

Note. 1-RM refers to the actual tested one-repetition maximums of participants. 2-RML, 6-RML, and 10-RML columns refer to the number of repetitions completed with their predicted weight loads from the 1-RM prediction chart. BP refers to bench press and LP refers to leg press. Independent t-tests revealed significant differences between males and females for bench press 1-RM, t (1,2) = -10.29 $p<.05$, and for leg press 1-RM, t (1,2) = -7.56 $p<.05$. The age of female and male participants was significantly different, t (1,2) = -3.27 $p<.05$.

Table 2

Summary of One-Sample T-tests Comparing Actual Number of Repetitions Completed to Predicted Number of Repetitions

Variable	Actual	Predicted	t-value	p
Females Bench Press				
2-RML	3.06 ± .53	2.00	2.00	.061
6-RML	7.89 ± .75	6.00	2.52	.022
10-RML	11.50 ± .63	10.00	2.39	.029
Females Leg Press				
2-RML	4.56 ± .72	2.00	3.55	.002
6-RML	9.72 ± .66	6.00	5.68	.000
10-RML	15.44 ± .83	10.00	6.57	.000
Males Bench Press				
2-RML	3.30 ± .33	2.00	3.90	.001
6-RML	7.90 ± .48	6.00	3.95	.001
10-RML	11.40 ± .41	10.00	3.44	.003
Males Leg Press				
2-RML	4.85 ± .72	2.00	3.94	.001
6-RML	10.25 ± .83	6.00	5.10	.000
10-RML	16.65 ± 1.12	10.00	5.96	.000

Note. Actual column figures are in repetitions completed (M ± SEM). 2-RML, 6-RML, and 10-RML refer to repetitions completed with predicted two-repetition maximum weight load, six-repetition maximum weight load, and ten-repetition maximum weight load, respectively. Predicted column is the number of repetitions predicted by the 1-RM

Prediction Chart with the corresponding weight load. One-sample t-tests for the bench press revealed significant differences between repetitions completed and predicted repetitions in female participants at the 6-RM weight load $t(1,2) = 2.52$ $p < .05$, and the 10-RM weight load, $t(1,2) = 2.39$ $p < .05$. In male participants, significant differences existed in the bench press exercise between repetitions completed and repetitions predicted at the 2-RM weight load $t(1,2) = 3.90$ $p < .05$, the 6-RM weight load $t(1,2) = 3.95$ $p < .05$, and the 10-RM weight load $t(1,2) = 3.44$ $p < .05$. In female participants, there was a significant difference in repetitions completed and repetitions predicted in the leg press exercise at the 2-RM workload $t(1,2) = 3.55$ $p < .05$, the 6-RM workload $t(1,2) = 5.68$ $p < .05$, and the 10-RM workload $t(1,2) = 6.57$ $p < .05$. In the leg press, there was a significant difference in the number of repetitions completed and repetitions predicted at the 2-RM workload $t(1,2) = 3.94$ $p < .05$, the 6-RM workload $t(1,2) = 5.10$ $p < .05$, and the 10-RM workload $t(1,2) = 5.96$ $p < .05$.

Table 3

Two-way Analysis of Variance Comparing the Number of Repetitions Completed for Bench Press and Leg Press in Females and Males Using the 2-RM Workload

	Bench Press	Leg Press
Females (n=18)	3.06 ± .53	4.56 ± .72
Males (n=20)	3.30 ± .33	4.85 ± .72

Note. Values are repetitions completed and represent the $M \pm SEM$. Two-way analysis of variance revealed that significantly more repetitions were completed in the leg press exercise at the 2-RM workload F (1,2) 6.55 $p < .05$, although dependent t-tests indicated no significant difference in males t (1,2) = -1.86 p=.08, or females t (1,2) = -1.78 p= .09.

Table 4

Two-way Analysis of Variance Comparing the Number of Repetitions Completed for Bench Press and Leg Press in Females and Males Using the 6-RM Workload

	Bench Press	Leg Press
Females (n=18)	7.89 ± .75	9.72 ± .66
Males (n=20)	7.90 ± .48	10.25 ± .83

Note. Values are repetitions completed and represent M ± SEM. Two-way analysis of variance revealed that significantly more repetitions were completed in the leg press exercise than the bench press at the 6-RM weight load F (1,2) = 9.113 $p < .05$. T-tests for dependent samples revealed no significant difference between repetitions completed t (1,2) = -1.94 $p = .08$ for males, but females completed significantly more repetitions in the leg press t (1,2) = -2.32 $p < .05$ than the bench press.

Table 5

Two-way Analysis of Variance Comparing the Number of Repetitions Completed for Bench Press and Leg Press in Females and Males Using the 10-RM Workload

	Bench Press	Leg Press
Females (n=18)	11.50 $\pm$ .63	15.44 $\pm$ .83
Males (n=20)	11.40 $\pm$ .41	16.65 $\pm$ 1.12

Note. Values are for repetitions completed and represent $M \pm SEM$. Two-way analysis of variance revealed that significantly more repetitions were completed on the leg press at the 10-RM load $F\ (1,2) = 33.282$ $p < .05$. Dependent t-tests revealed the same significant difference, $t\ (1,2) = -4.21$ $p < .05$ in males, and $t\ (1,2) = -4.96$ $p < .05$ in females at the 10-RM workload.

Table 6

Two-way Analysis of Variance Comparing the Differences in the Number of Repetitions Completed in the Bench Press Exercise and the Predicted Number of Repetitions for the 2-RM Workload, 6-RM Workload, and 10-RM Workload in Females and Males

	2-RM Workload	6-RM Workload	10-RM Workload
Females	1.06 ± .53	1.89 ± .75	1.50 ± .63
Males	1.30 ± .33	1.90 ± .48	1.40 ± .41

Note. Values are in repetitions completed above those predicted by the 1-RM Prediction Chart and represent M ± SEM. No significant differences were found.

Table 7

Two-way Analysis of Variance Comparing the Differences in the Number of Repetitions Completed in the Leg Press Exercise and the Predicted Number of Repetitions for the 2-RM Workload, 6-RM Workload, and 10-RM Workload in Females and Males

	2-RM Workload Repetition Differ.	6-RM Workload Repetition Differ.	10-RM Workload Repetition Differ.
Females (n=18)	2.56 ± .72	3.72 ± .66	5.44 ± .83
Males (n=20)	2.85 ± .72	4.25 ± .83	6.65 ± 1.12

Note. Values are in repetitions completed above those predicted by the 1-RM Prediction Chart and represent M ± SEM. A two-way analysis of variance revealed that a significant difference existed between the repetitions completed above those predicted across workloads F (1,2) = 8.12 $p < .05$. One-way analysis of variance revealed a significant difference across workloads in females F (1,2) = 3.87 $p < .05$. One-way analysis of variance revealed a significant difference across workloads in males F (1,2) = 4.50 $p < .05$. Tukey post hoc analyses revealed that the significant difference in the number of repetitions completed above those predicted existed between the 2-RM workload and 10-RM workload in both the male and female participants.

Discussion

The first null hypothesis of no statistically significant difference between repetitions completed and repetitions predicted at the 2-RM workload was rejected for the leg press in males ($\underline{M}$= 4.85, $\underline{p}$< .01) and females ($\underline{M}$= 4.56, $\underline{p}$< .01). At the 2-RM workload on the bench press, males completed significantly more repetitions ($\underline{M}$= 3.30, $\underline{p}$< .01) than predicted. In female participants, there was no significant difference in repetitions completed in the bench press ($\underline{M}$=3.06, $\underline{p}$ = .06).

The second null hypothesis of no significant difference in repetitions completed and repetitions predicted at the 6-RM workload was statistically rejected for males and females in the leg press and bench press exercises. Females completed significantly more repetitions in the bench press ($\underline{M}$= 7.89, $\underline{p}$< .05) and leg press ($\underline{M}$= 9.72, $\underline{p}$< .01) than predicted. Males completed significantly more repetitions in the bench press ($\underline{M}$= 7.90, $\underline{p}$< .01) and the leg press ($\underline{M}$= 10.25, $\underline{p}$<.01) than predicted.

The third null hypothesis of no significant difference in repetitions completed and repetitions predicted at the 10-RM workload was statistically rejected in males and females in the leg press and bench press exercises. Females completed significantly more repetitions in the bench press ($\underline{M}$= 11.50, $\underline{p}$< .05) and the leg press ($\underline{M}$= 15.44, $\underline{p}$< .01) than predicted. Males completed significantly more repetitions in the bench press ($\underline{M}$= 11.4, $\underline{p}$< .01) and leg press ($\underline{M}$= 16.65, $\underline{p}$< .01) than predicted.

T-tests revealed no significant differences between males and females in the number of repetitions completed at the 2-RM, 6-RM or 10-RM workloads ($\underline{p}$ levels all above .40).

Analysis of variance confirmed this ($F = .977$, $p = .33$). However, analysis of variance revealed that a significant difference existed between the number of repetitions completed above those predicted across workloads. Tukey post hoc analyses revealed that there were significant differences in repetitions completed above those predicted in males and females between the 2-RM workload and 10-RM workload on the leg press exercise (Table 7).

Across all participants (n=38), significant differences existed in the number of repetitions completed at all three workloads between the bench press and leg press. Analysis of variance revealed that significantly more repetitions were completed at the 2-RM workload on the leg press ($F = 6.55$, $p < .05$) than the bench press. At the 6-RM workload, significantly more repetitions were completed on the leg press ($F = 9.11$, $p < .01$) than the bench press. At the 10-RM workload, significantly more repetitions were completed on the leg press ($F = 33.28$, $p < .01$) than the bench press.

Within the female participants, there were no significant differences between bench press and leg press in repetitions completed at the 2-RM or 6-RM workloads. At the 10-RM workload, females completed significantly more repetitions on the leg press ($t = -4.21$, $p < .01$) than the bench press. This is in agreement with Hoeger et al. (1990) who concluded that using selected percentages of 1-RM (60% and 80%) did not yield the same number of repetitions completed to failure across different exercises.

Within the male participants, there was no significant difference between bench press and leg press in repetitions completed at the 2-RM workload. Males completed significantly more repetitions on the leg press at the 6-RM workload (t= -2.32, p< .05) and the 10-RM workload (t= -4.96, p< .01) than the bench press. This is in agreement with Hoeger et al. (1990) who found that participants completed 1.6 times more repetitions on the leg press than the bench press at 80% of 1-RM and 1.7 times as many at 60% of 1-RM.

Bench press one-repetition maximum value in pounds for males (M= 214.35, SEM= 12.26) was significantly higher than the females (M= 77.33, SEM= 3.31) (t= -10.29, p< .01). Leg press one-repetition maximum value in pounds was significantly higher in the males (M= 668.80, SEM= 31.16) than in the females (M= 398.72, SEM= 14.70) (t= -7.56, p< .01).

Chapter 5

SUMMARY, CONCLUSIONS and RECOMMENDATIONS

Summary

The purpose of this study was to determine if submaximal workloads can be determined from a tested one-repetition maximum figure using the table entitled "Estimating One-Repetition Maximum" by Wathen (1994). If statistically accurate, this table would allow for easy construction of training programs for experienced lifters based on their tested one-repetition maximum levels, and hence challenge lifters to complete the specified number of repetitions without performing sets with excessively high workloads or excessively high repetitions.

Participants (n=38) consisted of 18 female and 20 male experienced weight lifters who were free of any injury or health problems that could affect their performance. Participants were tested twice approximately 48-72 hours apart. On test day 1, informed consent and medical history/training questionnaires were filled out. Participants warmed up with light weights and then were tested to determine their 1-RM level on the leg press and bench press exercises. On test day 2, participants warmed up and then completed repetitions to momentary muscular failure with their predicted 2-RM, 6-RM and 10-RM workloads from Wathen (1994) on both the leg press and bench press.

Males completed significantly more repetitions than the chart predicts at the 2-RM workload ($p < .01$), the 6-RM workload ($p < .01$) and the 10-RM workload ($p < .01$) for the bench press. On the leg press males completed significantly more repetitions at the 2-RM workload ($p < .01$), the 6-RM workload ($p < .01$) and the 10-RM workload ($p < .01$). This is in agreement with Ware et al. (1995) who found that male athletes completed an average of 13.9 repetitions to failure on bench press and 17.4 repetitions to failure on the squat with workloads of approximately 70% of their 1-RM. Wathen (1994) predicts that approximately 11 repetitions would be completed with 70% of the lifter's 1-RM value.

Females completed significantly more repetitions than the chart predicts at the 2-RM workload ($p < .01$), the 6-RM workload ($p < .01$) and the 10-RM workload ($p < .01$) on the leg press. On the bench press, females completed significantly more repetitions than predicted at the 6-RM ($p < .05$) and 10-RM ($p < .05$)workloads. At the 2-RM workload, females completed more repetitions than predicted ($M = 3.06$, $SEM = .53$), but this difference was not found to be significant ($p = .06$).

There were no significant differences between males and females in repetitions completed at any workload on either exercise. This indicates that the same method, but not the same percentages reported by Wathen (1994), of predicting submaximal workloads from tested 1-RM values can be used for bench press and leg press across genders.

Since participants completed more repetitions to momentary muscular failure than predicted, this suggests that using tested 1-RM values in conjunction with the one-repetition maximum chart by Wathen (1994) would yield workloads that would not challenge lifters unless they performed significantly more repetitions than prescribed. This can cause problems if a program is designed to increase performance using one energy system, while another energy system is the primary contributor to the work effort. In addition, other program goals may not be effectively achieved when using an inappropriate number of repetitions per set for a given weight. Even though the difference in females in bench press at the 2-RM level was found to be insignificant ($p = .06$), the majority of the participants were capable of completing at least one more repetition than predicted. Since working to failure is particularly important at lower repetition workloads in lifters attempting to gain strength and power, the results of this study have important implications.

Problems would arise when using the 1-RM prediction chart (Wathen, 1994) to predict 1-RM level from submaximal repetitions to failure. Since the present study did not perform actual 2-RM, 6-RM and 10-RM testing, the participants would have had actual RM levels equal to or above the predicted levels from the chart. For example, if the participant completed two repetitions with a predicted 2-RM of 75 lb, she/he might have been able to complete two repetitions with 78 lb as well. This would mean that 78 lb is the participant's tested 2-RM. Since the participant completed two repetitions with 75 lb, you know the actual 2-RM value would not be less than 75 lb. Table 8 illustrates the difference between actual 1-RM values and those that would have been predicted from the submaximal workload efforts on the leg press.

Table 8

Actual and Predicted 1-RM Values for the Leg Press and Bench Press

	Actual 1-RM	2-RM Predicted 1-RM	6-RM predicted 1-RM	10-RM Predicted 1-RM
Males LP	668.80	723.97	766.05	864.30
Females LP	398.72	428.02	448.69	489.25
Males BP	214.35	222.07	227.28	225.07
Females BP	77.33	79.59	81.97	81.49

Note. These figures are based on the 1-RM level that would have been predicted from the repetitions completed to failure at the predicted 2-RM, 6-RM and 10-RM workloads. Since Wathen (1994) follows a linear prediction trend, it is possible to predict 1-RM values from M values of repetitions completed to failure. All figures are represented by M only. Two-RM predicted, 6-RM predicted and 10-RM predicted column values are based on what 1-RM would have been predicted based on how many repetitions to failure were completed with the participants' predicted 2-RM, 6-RM and 10-RM workloads respectively.

Table 8 indicates that linear prediction models for RM values may be increasingly inaccurate as the RM levels increase. This trend held true for both the leg press and bench press in the present study. Prediction trends for other exercises and/or other populations may be different. Analysis of variance confirmed that there were significantly more repetitions completed above those predicted with the 10-RM workload than the 2-RM workload (F (1,2) = 8.12, $p < .01$) on the leg press. This is in agreement with Stone & O'Bryant (1987), Ware et al. (1995), and Brzycki (1993).

The use of prediction equations combined with heavier workloads (e.g., 3-RM or 4-RM) is more accurate than 1-RM charts for predicting maximum strength levels. The equations, however, tend to be cumbersome and vary in accuracy between different exercises.

The present study suggests that using lower RM workloads yields a more accurate prediction of 1-RM values. This is in agreement with LeSuer et al. (1997) who found that estimating 1-RM values from prediction equations is more accurate when using less than ten repetitions to failure. Ware et al. (1995) concluded that using higher repetitions to failure is not an accurate means of predicting 1-RM values. This may be due to a change in energy systems when decreasing from heavier workloads (e.g., 3-RM) to lighter workloads (e.g., 10-RM).

The use of 1-RM prediction charts may be more accurate for single joint exercises. Madlena (1996) found that RPE levels were significantly higher in single-joint exercises, and participants completed significantly fewer repetitions to failure at submaximal workloads compared to multi-joint exercises. However, Fleck & Kraemer (1987) suggested that 1-RM prediction charts are more accurate with multiple-joint exercises that recruit larger muscle groups.

The compilation of an RM prediction model that is accurate across different exercises and different populations is not likely. Factors such as the number of muscles recruited, the psychological attitudes towards lifting to failure on different exercises, and variations in muscle fiber type between upper body and lower body may all affect the accuracy of prediction models. For example, working to failure on the squat exercise is more likely to be more intimidating than biceps curls. Scientists must consider that simplifying complex relationships into an easy-to-use model or chart is not always prudent.

Conclusions

From the data collected in this research, the following conclusions are made.

1. The use of the 1-RM prediction chart (Wathen, 1994) for prescribing submaximal workloads from submaximal repetitions to failure is statistically inaccurate for the bench press and leg press exercises in experienced adult weight lifters.
2. The 1-RM prediction chart by Wathen (1994) tends to predict submaximal workloads that are too light for the lifter to achieve momentary muscular failure at the prescribed number of repetitions. This can limit the effectiveness of resistance training programs designed to utilize a specific energy system or meet specific goals, and may reduce the gains achieved by the lifter.

3. The 1-RM chart tends to overpredict maximum strength levels in experienced adult weight lifters when using submaximal repetitions to failure. This held true at the 2-RM, 6-RM and 10-RM levels on both the leg press and bench press exercises.
4. The prediction of maximal strength levels using linear prediction models is not prudent. Lifters tend to complete a higher number of repetitions above the number predicted as the RM level increases (i.e., resistance decreases). Performing resistance training to momentary muscular failure with lower RM workloads (e.g., 2-RM or 3-RM) may be more accurate for predicting 1-RM levels.
5. Strength coaches wishing to assess 1-RM levels for their athletes should perform actual 1-RM testing with healthy athletes. If athletes fall into a high risk category for performing 1-RM testing, then the focus of their resistance training program should not be maximal strength at that time.

Recommendations

1. Fitness professionals must stress to their clients that prediction models are only a rough estimate of RM values. If clients are completing a different number of repetitions than the number prescribed, then they should adjust their workloads accordingly. As they make progress, clients must learn to increase their workload to stay within the prescribed repetition range.
2. Future research needs to examine the accuracy of 1-RM prediction charts for exercises other than the bench press and leg press.

3. Future research should focus on the accuracy of 1-RM prediction charts for populations of different ages and experience levels, across commonly used exercises.
4. Future research needs to be done examining the possibility of an accurate nonlinear prediction equation or chart for multiple-joint exercises commonly used by athletes such as the bench press, squat, leg press or power cleans.
5. Based on the results of this study, 1-RM testing or prediction should be avoided when designing resistance training programs for nonathletes. Because maximum strength levels vary from week to week, and multiple exercises are usually prescribed, the lifter needs to be able to adjust workload levels frequently. Workloads can be adjusted through trial and error that allow the lifter to complete the specified number of repetitions to failure.
6. Based on the results of this study, the use of 1-RM prediction charts and equations are not useful when working with athletes. If fitness professionals want to monitor the strength of their athletes, they should use 1-RM testing. Athletes should have no problem adjusting their workloads to complete the desired number of repetitions to momentary muscular failure.

Weaknesses of the Study

1. Strength testing that requires maximum effort may have many associated psychological variables that affect the results including fear of injury and discomfort from using workloads heavier than those to which they are accustomed.

2. Assessment of 1-RM levels must be done in a carefully controlled environment because of the number of external variables that may affect performance. These variables include, but are not limited to, rest intervals, days off between testing sessions, rest habits, and the participants' attitudes towards maximal efforts with weight training. Even experienced lifters may have an adverse reaction to lifting to muscular failure with heavy weights. It is hard to predict how accurately participants followed their testing day and rest day instructions.
3. The accuracy of data collection may be affected by daily variations in strength levels.

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APPENDIX A
Estimating One-Repetition Maximum

Adapted from:

Baechle, T. (1994). Essentials of strength training and conditioning. Champaign, IL: Human Kinetics.

% of 1-RM	100.0	93.5	91.0	88.5	86.0	83.5	81.0	78.5	76.0	73.5
Repetitions	1	2	3	4	5	6	7	8	9	10
Weight	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lifted:	5.0	4.7	4.6	4.4	4.3	4.2	4.1	3.9	3.8	3.7
	10.0	9.4	9.1	8.9	8.6	8.4	8.1	7.9	7.6	7.4
	15.0	14.0	13.7	13.3	12.9	12.5	12.2	11.8	11.4	11.0
	20.0	18.7	18.2	17.7	17.2	16.7	16.2	15.7	15.2	14.7
	25.0	23.4	22.8	22.1	21.5	20.9	20.3	19.6	19.0	18.4
	30.0	28.1	27.3	26.6	25.8	25.1	24.3	23.6	22.8	22.1
	35.0	32.7	31.9	31.0	30.1	29.2	28.4	27.5	26.6	25.7
	40.0	37.4	36.4	35.4	34.4	33.4	32.4	31.4	30.4	29.4
	45.0	42.1	41.0	39.8	38.7	37.6	36.5	35.3	34.2	33.1
	50.0	46.8	45.5	44.3	43.0	41.8	40.5	39.3	38.0	36.8
	55.0	51.4	50.1	48.7	47.3	45.9	44.6	43.2	41.8	40.4
	60.0	56.1	54.6	53.1	51.6	50.1	48.6	47.1	45.6	44.1
	65.0	60.8	59.2	57.5	55.9	54.3	52.7	51.0	49.4	47.8
	70.0	65.5	63.7	62.0	60.2	58.5	56.7	55.0	53.2	51.5
	75.0	70.1	68.3	66.4	64.5	62.6	60.8	58.9	57.0	55.1
	80.0	74.8	72.8	70.8	68.8	66.8	64.8	62.8	60.8	58.8
	85.0	79.5	77.4	75.2	73.1	71.0	68.9	66.7	64.6	62.5
	90.0	84.2	81.9	79.7	77.4	75.2	72.9	70.7	68.4	66.2
	95.0	88.8	86.5	84.1	81.7	79.3	77.0	74.6	72.2	69.8
	100.0	93.5	91.0	88.5	86.0	83.5	81.0	78.5	76.0	73.5
	105.0	98.2	95.6	92.9	90.3	87.7	85.1	82.4	79.8	77.2
	110.0	102.9	100.1	97.4	94.6	91.9	89.1	86.4	83.6	80.9
	115.0	107.5	104.7	101.8	98.9	96.0	93.2	90.3	87.4	84.5
	120.0	112.2	109.2	106.2	103.2	100.2	97.2	94.2	91.2	88.2
	125.0	116.9	113.8	110.6	107.5	104.4	101.3	98.1	95.0	91.9
	130.0	121.6	118.3	115.1	111.8	108.6	105.3	102.1	98.8	95.6
	135.0	126.2	122.9	119.5	116.1	112.7	109.4	106.0	102.6	99.2
	140.0	130.9	127.4	123.9	120.4	116.9	113.4	109.9	106.4	102.9
	145.0	135.6	132.0	128.3	124.7	121.1	117.5	113.8	110.2	106.6
	150.0	140.3	136.5	132.8	129.0	125.3	121.5	117.8	114.0	110.3
	155.0	144.9	141.1	137.2	133.3	129.4	125.6	121.7	117.8	113.9
	160.0	149.6	145.6	141.6	137.6	133.6	129.6	125.6	121.6	117.6
	165.0	154.3	150.2	146.0	141.9	137.8	133.7	129.5	125.4	121.3
	170.0	159.0	154.7	150.5	146.2	142.0	137.7	133.5	129.2	125.0
	175.0	163.6	159.3	154.9	150.5	146.1	141.8	137.4	133.0	128.6
	180.0	168.3	163.8	159.3	154.8	150.3	145.8	141.3	136.8	132.3
	185.0	173.0	168.4	163.7	159.1	154.5	149.9	145.2	140.6	136.0
	190.0	177.7	172.9	168.2	163.4	158.7	153.9	149.2	144.4	139.7
	195.0	182.3	177.5	172.6	167.7	162.8	158.0	153.1	148.2	143.3
	200.0	187.0	182.0	177.0	172.0	167.0	162.0	157.0	152.0	147.0
	205.0	191.7	186.6	181.4	176.3	171.2	166.1	160.9	155.8	150.7
	210.0	196.4	191.1	185.9	180.6	175.4	170.1	164.9	159.6	154.4
	215.0	201.0	195.7	190.3	184.9	179.5	174.2	168.8	163.4	158.0
	220.0	205.7	200.2	194.7	189.2	183.7	178.2	172.7	167.2	161.7
	225.0	210.4	204.8	199.1	193.5	187.9	182.3	176.6	171.0	165.4
	230.0	215.1	209.3	203.6	197.8	192.1	186.3	180.6	174.8	169.1
	235.0	219.7	213.9	208.0	202.1	196.2	190.4	184.5	178.6	172.7
	240.0	224.4	218.4	212.4	206.4	200.4	194.4	188.4	182.4	176.4
	245.0	229.1	223.0	216.8	210.7	204.6	198.5	192.3	186.2	180.1
	250.0	233.8	227.5	221.3	215.0	208.8	202.5	196.3	190.0	183.8
	255.0	238.4	232.1	225.7	219.3	212.9	206.6	200.2	193.8	187.4
	260.0	243.1	236.6	230.1	223.6	217.1	210.6	204.1	197.6	191.1
	265.0	247.8	241.2	234.5	227.9	221.3	214.7	208.0	201.4	194.8
	270.0	252.5	245.7	239.0	232.2	225.5	218.7	212.0	205.2	198.5
	275.0	257.1	250.3	243.4	236.5	229.6	222.8	215.9	209.0	202.1
	280.0	261.8	254.8	247.8	240.8	233.8	226.8	219.8	212.8	205.8
	285.0	266.5	259.4	252.2	245.1	238.0	230.9	223.7	216.6	209.5
	290.0	271.2	263.9	256.7	249.4	242.2	234.9	227.7	220.4	213.2
	295.0	275.8	268.5	261.1	253.7	246.3	239.0	231.6	224.2	216.8
	300.0	280.5	273.0	265.5	258.0	250.5	243.0	235.5	228.0	220.5

% of 1-RM	100.0	93.5	91.0	88.5	86.0	83.5	81.0	78.5	76.0	73.5
Repetitions	1	2	3	4	5	6	7	8	9	10
Weight Lifted:	305.0	285.2	277.6	269.9	262.3	254.7	247.1	239.4	231.8	224.2
	310.0	289.9	282.1	274.4	266.6	258.9	251.1	243.4	235.6	227.9
	315.0	294.5	286.7	278.8	270.9	263.0	255.2	247.3	239.4	231.5
	320.0	299.2	291.2	283.2	275.2	267.2	259.2	251.2	243.2	235.2
	325.0	303.9	295.8	287.6	279.5	271.4	263.3	255.1	247.0	238.9
	330.0	308.6	300.3	292.1	283.8	275.6	267.3	259.1	250.8	242.6
	335.0	313.2	304.9	296.5	288.1	279.7	271.4	263.0	254.6	246.2
	340.0	317.9	309.4	300.9	292.4	283.9	275.4	266.9	258.4	249.9
	345.0	322.6	314.0	305.3	296.7	288.1	279.5	270.8	262.2	253.6
	350.0	327.3	318.5	309.8	301.0	292.3	283.5	274.8	266.0	257.3
	355.0	331.9	323.1	314.2	305.3	296.4	287.6	278.7	269.8	260.9
	360.0	336.6	327.6	318.6	309.6	300.6	291.6	282.6	273.6	264.6
	365.0	341.3	332.2	323.0	313.9	304.8	295.7	286.5	277.4	268.3
	370.0	346.0	336.7	327.5	318.2	309.0	299.7	290.5	281.2	272.0
	375.0	350.6	341.3	331.9	322.5	313.1	303.8	294.4	285.0	275.6
	380.0	355.3	345.8	336.3	326.8	317.3	307.8	298.3	288.8	279.3
	385.0	360.0	350.4	340.7	331.1	321.5	311.9	302.2	292.6	283.0
	390.0	364.7	354.9	345.2	335.4	325.7	315.9	306.2	296.4	286.7
	395.0	369.3	359.5	349.6	339.7	329.8	320.0	310.1	300.2	290.3
	400.0	374.0	364.0	354.0	344.0	334.0	324.0	314.0	304.0	294.0

APPENDIX B
Informed Consent Form

1. You are invited to participate in a study by John Gilligan, graduate student in exercise physiology at San Jose State University. This study is entitled "The Validity of 1-RM Prediction Charts for Predicting Maximal Strength in Experienced Adult Weightlifters".
2. I have been informed that this study's purpose is to determine if maximal strength level can be accurately determined using submaximal loads. The information may be used to construct effective exercise programs that can challenge individuals without compromising their safety.
3. If you decide to participate in the study, two testing sessions will be required in which subjects will be required to perform the leg press and bench press exercises until full muscle exhaustion has been reached. On day 1, the maximum weight the subject can successfully lift (maximum strength) will be determined on both exercises. On day 2, the subject will be required to complete sets until exhaustion with loads equaling 93.5% of maximum strength, 83.5% of maximum strength and 73.5% of maximum strength. These two test days will be approximately 48-72 hours apart, and will require approximately 1 hour for each session. Subjects will be required to abstain

Subject's initials:

from any form of weight training or strenuous cardiovascular exercise for at least 48 hours before testing on both days. Subjects must complete a medical history questionnaire to minimize any risks.

4. I understand that there are potential risks or discomforts involved with my participation. These risks may include musculoskeletal injuries, muscle soreness, and/or fatigue. If any pain or discomfort arises, I will inform the test administrator immediately.
5. I understand that there are benefits associated with my participation, including increased knowledge of weight training techniques, and exercise programming. I understand that in exchange for my participation, I will be entitled to complimentary fitness programming/counseling.
6. I understand that the results of this research project may be published or used during professional conferences, but that my name will be kept confidential at all times. In order to prevent my identity from being revealed, I will be assigned a subject number, and after testing, I will only be referred to by this subject number. The data derived from this research will be kept in a locked file cabinet to which only the researcher has access.
7. If you have any questions regarding the procedures, contact either John Gilligan (principal investigator) at (650) 428-0787, or Dr. Craig Cisar at

Subject's initials:

(408) 924-3018, Department of Human Performance, San Jose State University.

8. If you have any complaints regarding the procedures, direct them to Carol Christensen, Chair, Human Performance Department, San Jose State University, (408) 924-3010. Questions about research, subjects' rights, or research related injury may be presented to Nabil Ibrahim, Acting Associate Vice President for Graduate Studies and Research, at (408) 924-2480.

9. I understand that my participation in this study is entirely voluntary, and that I may withdraw from participating at any time. I understand that no service of any kind, to which I am entitled, will be lost or jeopardized should I choose not to participate.

I have read this form and understand the test procedures in which I will participate. I consent to participate in this study, and understand that I may withdraw at any time. I also agree that I have received a copy of this form for my records.

Signature:________________________________ Date:____________

Print Name:________________________________

Investigator's Signature:______________________ Date:____________

APPENDIX C

Health/Training History Questionnaire

Please complete the following health/ training history questionnaire to the best of your ability. If you have any concerns, please contact your personal physician. The information contained herein will be used to determine your eligibility to participate in this research study.

Name______________________________ Date__________________

Age______________ Phone Number__________________

Home Address____

____

Personal Physician's name and phone number___________________________

Person to contact in case of an emergency_____________________________

phone number___________________________

PLEASE DO NOT WRITE BELOW THIS LINE

Subject Code Number_____________

1. Do you suffer from any joint pain or discomfort? Yes No

2. Do you have a history of heart disease? Yes No

3. Have you ever had a stroke? Yes No

4. Do you have a history of high blood pressure (hypertension)? Yes No

5. Has your doctor ever advised you to avoid exercising? Yes No

6. Have you had any recent surgery or medical procedures? Yes No

7. If you answered yes to #5, please explain ______________________

8. Do you have any medical condition that prevents you from exercising? Yes No

9. How many months have you trained with weights in your lifetime? __________

10. How many times have you lifted weights in the last three months (approximately)?

    ____________?

11. Do you have experience with the leg press and bench press exercises? Yes No

12. Is there any reason for you to believe that weight lifting is of risk to you? Yes No

13. If you answered yes to #12, what was your reasoning? ____________________

If you have any questions regarding your health or ability to perform strength testing, please consult your physician. Your participation in this study is entirely voluntary. Thank you for your time and effort.

APPENDIX D

Test Disqualifications

1. Subject must abstain from any weight training or strenuous cardiovascular exercise for 48 hours prior to both test sessions.
2. Subject must be in good health and free from hypertension, joint injury, heart disease, or any other health risk.
3. On the bench press exercise, subject must use slow and controlled form. A minimum of a 3 second count is required when lowering the bar to the chest. No bouncing of the bar will be allowed. The bar must hit between the clavicles (collar bones) and the bottom of subject's chest plate (sternum xiphoid process). Subject must hesitate briefly, and when cued must return the bar to full elbow extension.
4. Hand grip width will be between 20-30 cm wider than shoulder width (measured from acromian process to acromian process). Tape markers will mark where subject's hands will be placed on each lift.
5. On the leg press exercise, subject must use a slow and controlled motion with a minimum of a 3 second lowering phase. Sled will be lowered to a 90° knee angle (90° of knee flexion), as measured by tape markers. Subject must hesitate briefly, and when cued must return the sled to full knee extension. Subject's feet must be shoulder width apart and parallel to each other throughout the lift.

APPENDIX E
Recording Form

Subject Code #:	
Test Date/Time:	

PRE-TEST INFORMATION

Age: ____________________ **Resting BP:** ____________________

Last Exercise Date: ____________________ **Last Exercise Time:** ____________________

Shoulder Width: ____________________ **Bench Press Gripwidth:** ____________________

DAY 1: 1-RM TEST

	BENCH PRESS			LEG PRESS		
Trial	**Time**	**Wt Load (lb)**	**Successful?**	**Time**	**Wt Load (lb)**	**Successful?**
1			Yes No			Yes No
2			Yes No			Yes No
3			Yes No			Yes No
4			Yes No			Yes No
5			Yes No			Yes No
6			Yes No			Yes No

DAY 2: SUBMAXIMAL REPETITION TEST

	BENCH PRESS		LEG PRESS	
1-RM from Day 1:				
	Wt Load (lb)	**# of Reps**	**Wt Load (lb)**	**# of Reps**
Predicted 10-RM:				
Predicted 6-RM:				
Predicted 2-RM:				

ADDITIONAL NOTES

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