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Determination and Prediction of One Repetition Maximum (1RM): Safety Considerations

by

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Strength training is recommended for slowing age-dependent deterioration of muscular strength and for rehabilitating patients with muscle weakening illnesses. Reliable assessment of muscle strength is important for proper design of strength training regimes for prevention, rehabilitation, and sport. One repetition maximum (1RM) is an established measure of muscular strength and is defined as the value of resistance against which a given movement can be performed only once. Proper assessment of 1RM is time consuming, and may lead to muscle soreness as well as temporary deterioration of the function of the tested muscles. Attempts at indirect 1RM determination based on the maximum number of repetitions performed have predicted 1RM with a variable degree of accuracy. Cardiovascular safety has been neglected in 1RM determination, although arterial blood pressure increases considerably when exercising against maximal or near maximal resistance. From the perspective of cardiovascular safety, favorable 1RM measurement methods should avoid performance of repetitions until failure; movement against high resistance and muscle fatigue both increase blood pressure. Although such techniques are likely less accurate than the current methods, their prediction accuracy be sufficient for therapeutic strength training.

Key words: *strength exercise, hemodynamic response, blood pressure*

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Strength training

The aim of strength training is to increase muscle strength. To this end muscles have to move against an opposing force in a process called resistance, hence such training is also termed resistance training. The established measure of resistance or load is one repetition maximum (1RM), defined as the load for which only one full repetition, i.e., a sequence of movements ending back in the starting position, can be performed. Consequently 1RM is the upper load limit; if smaller fractions are used, more repetitions can be performed. For example, an 80% 1RM load typically allows for a maximum of 8 repetitions. The maximum number of repetitions performed with a given load can also be used for notation; thus if with 80% 1RM a maximum of 8 repetitions can be performed, the load can be also denoted as 8RM. It should be noted that 1RM refers to the current capabilities of a given person; thus the absolute load value of 1RM is different for different persons.

Repetitions performed continuously without stopping are termed a set. Loads allowing 1 to 6 repetitions most effectively increase strength, whereas loads allowing more than 25 repetitions are barely effective or not effective at all (Atha 1981). Increasing muscle strength requires at least 50% 1RM load, whereas 80% 1RM may be needed to increase bone mineral density (Vincent and Braith 2002).

Strength training as therapy

Strength training is an efficient therapy against age-dependent loss of muscle strength and muscle mass, termed sarcopenia, as well as against muscle weakness due to illness-induced inactivity. The maximum muscle strength declines gradually at 1.5% per year in the sixth and seventh decades of life. Subsequently, the loss rate doubles such that very old persons retain half or less than half of their peak strength (Doherty 2003). Age-dependent loss of maximal strength brings elderly persons towards their threshold for dependence (Young and Skelton 1994, Rantanen and Avela 1997, Kozakai et al. 2000), and increases their risk of falling (Morley et al. 2001).

Strength training reverses sarcopenia to some extent at any age. The degree of strength recovery after strength training ranged from over 130% in a group of very elderly subjects (85-97 years, Harridge et al. 1999) to below 20% (Roelants et al. 2004, Reeves et al. 2004). Such disparate results may be explained by differences in participants' age, pre-training status, possible increases in weight-lifting capacity due to neural adaptation during the familiarization period, and training protocols (Reeves et al.2004).

Strength training may also favorably affect bone density and in this respect may be superior to endurance training. However, strength training is likely inferior in its ability to increase maximal oxygen consumption, lower resting arterial pressure, improve lipid profile, and reduce hypertension and obesity (Pollock and Evans 1999).

Performing 1RM determination

Determination of 1RM is the process of identifying a load that can moved through the entire range of movement only once. This type of exercise is classified as isotonic contraction, as the external load remains constant thus implying constant tension of muscles. Even if the design of the testing machine ensures constant torque over the whole range of movement, the tested person will encounter a weak point, the so-called "sticking point". This is because the external force developed by the limb depends on the biomechanics of the movement, and additionally the strength of muscles at given level of stimulation depends on their length. It follows that neural stimulation of the muscles during movement needs to be highest at the sticking point, and 1RM indirectly measures the ability to overcome this point (DeVries and Housh 1994, Sale 1991).

Measurement of the true value of 1RM is also impeded by the lack of available information about rate of force development, contraction velocity, and acceleration; thus knowledge of the 1RM value may be insufficient in the context of an athlete's specific needs (Abernethy et al. 1995).

Determination of 1RM proceeds over subsequent trials in which the amount of weight to be lifted is increased stepwise until the subject fails to produce a full-range movement. As the procedure requires multiple repetitions, the results may be confounded by fatigue (Chandler et al. 1997).

Several factors are important for optimizing 1RM performance, including choice of starting weight, rest intervals between attempts, increments in weight, and criteria for acceptable lifting. Brown and Wier (2001) proposed the following standardized procedures for 1RM determination based on previous recommendations (Stone and O'Bryant 1987, Kraemer and Fry 1991, Wagner et al. 1992, Weir et al. 1994).

The subject should perform a 3-5 minute light general warm-up involving the muscles to be tested. The subject should then perform static stretching exercises of these muscles followed by a specific warm-up consisting of 8 repetitions at approximately 50% and then 3 repetitions at 70% of 1RM, assuming that 1RM can be estimated from the number of repetitions performed at the given weight. The subject will then perform single repetitions with increasingly heavier loads until failure. It is desirable that at least two weight increments are tried before the failed lift where the optimal number of single repetitions ranges from 3 to 5. After the failed lift, one more attempt should be made with a load calculated as the sum of the heaviest load lifted plus the half of difference between that load and the load with the failed lift.

The outlined above process of direct 1RM determination is time consuming, and may lead to muscle soreness as well as temporary deterioration of the function of the tested muscles. Chapman et al (1998) reported that 3 testers needed over 6 hours to determine the bench press 1RM in 98 football players. Ploutz-Snyder and Giamis (2001) found that the number of sessions necessary to establish consistent 1RM values for knee extension with a very high accuracy (1 kg; 0.7 -1.3% of measurement) between testing sessions, was *2* to *5* and *7* to 10 sessions in young and elderly women, respectively.

It has been argued by Braith et al. (1993) that 1RM evaluation should not be performed by novice lifters, because maximum lifting by a person without any previous experience in weight lifting may cause muscle soreness and even more serious injury. This has been confirmed by Dohoney et al. (2002), who found that in a group of 34 healthy men, six reported limited exercise ability and 22 noticeable muscle soreness after direct 1RM assessment.

The danger of injuries may be of particular concern in those who benefit most from strength training, i.e., the elderly. Injuries in a range of 2.4 -19% were reported by Pollock et al. (1999) and Shaw et al. (1995); the latter group also found a 70% incidence of muscle soreness. However, Rydwik et al. reported a much lower rate of adverse effects of 1RM assessment in elderly (15% of soreness and no injury) (2007).

Prediction of 1RM based on number of repetitions performed with submaximal loads

The value of 1RM may be predicted based on the number of repetitions a subject can perform with a submaximal load. Typically, 1RM prediction based on the number of repetitions performed with submaximal loads has been applied to the bench press. LeSuer et al. (1997) found that two prediction equations of seven evaluated gave relatively low differences between 1RM predicted and determined directly. These were: 1RM = mass of submaximal load · (100/(52.2 + 41.9 exp [-0.055 · number of repetitions])); Mayhew et al. (1992), and Wathen (1994): 1RM = mass of submaximal load (100/(48.8 + 53.8 exp [-0.075 · number of repetitions])). These equations were tested in 67 college students (males and females), and both were equally good in predicting 1RM: in average they overestimated directly determined bench press 1RM only by 0.5 kg, predicted and directly measured 1RM were highly correlated – $r^2 = 0.98$. The submaximal loads used allowed for maximally 10 repetitions. Accuracy of prediction using Wathen's equation was confirmed by Knutzen et al. (1999) in elderly subjects. There was no gender dependent difference in prediction accuracy of prediction equations (Mayhew et al. (1992).

Using 1RM prediction instead of direct determination significantly shortens the measurement process: Chapman et al (1998) found that instead of the 18 man-hours needed for direct 1RM determination in 98 persons, the same task could be accomplished in 2.5 man-hours when 1RM was predicted using the number of submaximal load lifts. Prediction of 1RM may also be beneficial for exercising the muscles. Dohoney et al. (2002) found no exercise limitation or muscle soreness after 4-6RM and 7-10RM strength assessment in contrast to the detrimental effects of direct 1RM determination.

Cardiovascular safety during 1RM determination

Avoidance of muscle soreness and limitation of exercise are typically used to justify the use of prediction techniques. However, avoidance of the more serious danger of cardiovascular events has remained relatively unnoticed.

Increased blood pressure remains major concern for strength training, especially in light of the rare but present risk of cerebral aneurysm rupture or subarachnoid hemorrhage (Haykowski et al. 2001, 2003). Therapeutically efficient strength training must be performed 2-3 times per week for about 20 min per session, thus the exposure to increased cardiovascular load is relatively short. High pressure during exercise remains the main concern for potential adverse effects.

During strength exercises, dramatic increases in blood pressure and heart rate have been observed (, MacDougall et al. 1985, Fleck and Dean 1987, Stone et al. 1991, Sale et al. 1993, Sale et al. 1994, Scharf et al. 1994). Though detailed picture of hemodynamic response to strength exercises remains uncertain, as well as the underlying mechanisms, some basic features were consistently reported by several authors (Niewiadomski et al. 2007). Both systolic and diastolic arterial pressures change rhythmically from almost normal to high levels during the phases of exercise; during the double-leg press, the peak systolic/diastolic pressure has been found to reach 320/250 mmHg in body builders (MacDougall et al. 1985). The peak pressure grows with subsequent repetitions, and after the last repetition blood pressure declines rapidly even below the pre-exercise level.

MacDougall et al. (1992) argued that the magnitude of blood pressure response depends mainly on the relative intensity of the effort; weight lifting performed by different persons at the same relative intensity produces similar increases in blood pressure despite individual differences in muscle size and absolute strength.

Interestingly, the smallest increase was observed at 1RM, whereas the responses to 90, 80, 70 and 50 % of 1RM were all greater and similar in magnitude. The number of repetitions performed to fatigue was not revealed, however it was likely smallest at 90% and greatest at 50% of 1RM. Given that the cessation of exercise repetitions resulted from voluntary fatigue, the similar response to different relative loads may have resulted from the same degree of muscle stimulation at the point of fatigue.

Relative effort may not be the only determinant of cardiovascular response during strength exercises. Fleck and Dean (1987) compared hemodynamic responses to strength exercises repeated to failure by body builders, novice weight-trained individuals, and sedentary controls at 90, 80, 70, and 50% of 1RM and at 1RM. Significantly weaker hemodynamic response as measured by peak blood pressure and peak heart rate was observed in body builders at the same relative load and much greater absolute load (almost double that in sedentary subjects).

The Valsalva maneuver often accompanies strength exercises; MacDougall et al. (1992) found that when force output was below 80% of maximal voluntary contraction (MVC), the Valsalva maneuver only occurred occasionally, whereas with heavier loads it became almost inevitable. Significantly, it was found that even when the Valsalva maneuver was absent at the beginning of repetitions with lighter loads, it appeared closer to the series end if the trainee continued to failure. Once the Valsalva maneuver appeared, the peak intrathoracic pressure progressively rose in concert with the systolic and diastolic pressures.

The hemodynamic response to strength exercises prompts consideration of the cardiovascular safety of both direct and indirect 1RM determination. Both direct and indirect 1RM determination requires subjects to perform repetitions until failure. This means that the maximal arterial pressure attained during the few last repetitions will be similar irrespective of the relative load used in the indirect method. Somewhat unexpectedly from the perspective of cardiovascular safety, direct 1RM determination appears to be less challenging, as smaller peak arterial pressure is expected. On the other hand, the direct method may require several isolated attempts, exposing the subject to several almost maximal load lifts. One drawback of direct 1RM determination is the high probability of performing the Valsalva maneuver when lifting or attempting to lift very heavy loads. However, Valsalva maneuvers are also likely to be performed when subjects approach their few last lifts even if the load is submaximal. Finally, persons who are novices in strength exercises may be exposed to a greater danger of cardiovascular events than those with experience because their hemodynamic response to the 1RM procedure will likely be greater.

Towards safer 1RM determination

From the cardiovascular perspective, both direct and indirect 1RM determination techniques represent challenges that may lead to dangerous outcomes. In order to determine the safer method, careful evaluation of hemodynamic responses accompanying 1RM determination should be performed. Safe 1RM determination should not require performance of repetitions until failure, as this appears to be the main source of the fully developed hemodynamic response. Rather, methods based on maximal voluntary contraction (MVC) determination should be attempted. MVC methods may potentially be much safer; if the subject can avoid performing the Valsalva maneuver, the cardiovascular response should only be controlled by central inhibition of the parasympathetic nervous system and consist of a moderate HR increase (about 100 beats/min) and subsequent rise in blood pressure (Seals and Victor 1991). However, MVC determination presents some disadvantages when compared to 1RM. The MVC value depends on the choice of point in the range of motion, and MVC at different points may be poorly correlated (Zeh et al. 1986, Murphy et al. 1995,). Furthermore, there are doubts whether the measurement of static strength relevant to dynamic performance (Wilson and Murphy 1988). A more complex approach could be applied that would combine more information such as changes in the rate of force development or even surface EMG assessment of increased motoneuron recruitment of motoneurons (Gandevia 2001).

We propose that hemodynamic response data should be included when performing any kind of maximal strength evaluation, but especially when strength training will be applied as a therapy. In this context, the aspect of required accuracy is worth mentioning; although in sports, highly accurate assessment of 1RM is indispensable for monitoring the efficacy of training, less accurate determination may suffice in therapy because the goal is only to determine an effective load for building muscular strength. Regardless, accurate 1RM measurement is also desirable in the therapeutic arena, as the ultimate goal is to increase muscular strength.

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