Journal of Strength and Conditioning Research, 2007, 21(2), 628–631

Brief Review

The Application of Training to Failure in Periodized Multiple-Set Resistance Exercise Programs

Jeffrey M. Willardson

Physical Education Department, Eastern Illinois University, Charleston, Illinois 61920.

Abstract. Willardson, J.M. The application of training to failure in periodized multiple-set resistance exercise programs. *J. Strength Cond. Res. 21(2):628–631. 2007.*—Few studies and reports in the body of literature have directly addressed the issue of whether resistance exercise sets should be performed to failure. Research has clearly demonstrated the superiority of performing multiple sets vs. single sets for increases in maximal strength. However, there is little direct evidence to decide conclusively whether or not multiple sets should be performed to failure. Therefore, the purpose of this research note was to discuss what is currently known concerning the application of training to failure and to stimulate further research on this topic. Although not essential for increases in muscular characteristics such as strength and hypertrophy, training to failure might allow advanced lifters to break through training plateaus when incorporated periodically into short-term microcycles. Because muscular hypertrophy is a key contributor to long-term increases in maximal strength, advanced lifters should consider training to failure occasionally. The potential mechanisms by which training to failure might provide an advantage are through greater activation of motor units and secretion of growth-promoting hormones. However, training to failure is not an effective stimulus without lifting at a sufficient intensity (percentage of 1 repetition maximum). Furthermore, training to failure should not be performed repeatedly over long periods, due to the high potential for overtraining and overuse injuries. Therefore, the training status and the goals of the lifter should guide the decision-making process on this issue.

Key Words. fatigue, motor unit recruitment, growth hormone, strength, hypertrophy

Introduction

When designing resistance exercise programs, many training variables must be considered for optimal results to occur (2). In a position stand, written for the American College of Sports Medicine, training variables such as the type of muscle action, load, volume, exercise selection, exercise order, rest periods, velocity of muscle action, and frequency were discussed and recommendations were made based on different goals (1). However, an issue not discussed, but also highly relevant, particularly when the goal is maximal strength or hypertrophy, is whether resistance exercise sets should be performed to muscular failure.

Much of what has been written concerning the benefits of training to failure may have originated from a marketing scheme connected with the sale of Nautilus equipment in the 1970s. However, power lifters and bodybuilders who followed lifting programs based on repetition maximums (RM) probably were training to failure (intentionally or at random) before this time period. There are few studies and reports in the body of literature that have directly addressed this issue (3, 6, 7, 9, 11, 14, 15). Therefore, the purpose of this research note will be to discuss what is currently known concerning the application of training to failure and to stimulate further research on this topic.

Muscular Failure Defined

Muscular failure can be defined as the point during a resistance exercise set when the muscles can no longer produce sufficient force to control a given load (3, 15). At this point, the set is ended and a period of rest ensues to allow for resynthesis of ATP and clearance of fatigue-producing substances (e.g., $H+$ ions). Muscular failure usually occurs during the concentric phase of a repetition; however, a set often can be extended through spotter-assisted repetitions, eccentric-phase only repetitions, or isometric holds.

Therefore, to describe a muscle as being maximally fatigued at the point of concentric failure is inaccurate, because the muscle is not entirely fatigued (3). A common technique among resistance trainers, upon reaching concentric failure, is to immediately reduce the resistance and continue performing repetitions. Because the muscles are not maximally fatigued, sufficient force can be produced to perform additional repetitions with less resistance. A previous study demonstrated that this technique provided a superior stimulus for increases in strength and hypertrophy due to increased secretion of growth hormone (4).

Rationale for Training to Failure

Performing sets to failure with heavy resistance may activate a greater number of motor units (3, 6, 11, 12, 14, 15). During a typical heavy resistance exercise set, the pattern of motor unit recruitment follows the size principle (12). A recruitment threshold exists whereby lower threshold motor units, composed of predominantly type I slow-twitch or type IIa fast-twitch muscle fibers are recruited first. As consecutive repetitions are performed, these motor units become progressively fatigued, at which point additional higher threshold motor units composed of predominantly type IIx fast-twitch muscle fibers are recruited (12).

Muscular failure occurs when all available motor units have fatigued to the point that sufficient force cannot be produced to move a given load beyond a critical joint angle or "sticking point" (3). Therefore, training to failure may provide greater stimulation to the highest threshold fast-twitch motor units, which are capable of the greatest increases in strength and hypertrophy (3, 6, 11, 12, 14). Although not training to failure with a heavy load would involve some recruitment of fast-twitch motor units, the highest threshold motor units may never be fully recruited, which could limit increases in strength and hypertrophy in advanced lifters.

Training to failure is not an effective stimulus without lifting at a sufficient intensity (percentage of 1RM) (9, 15). For example, training to failure at a relatively low intensity (30% 1RM), as is commonly practiced in Super Slow resistance training, will not result in maximal increases in strength and hypertrophy due to the recruitment of primarily slow-twitch motor units (1, 12). However, when a sufficient intensity is utilized (e.g., 80% 1RM), training to failure may provide an advantage when employed periodically within short-term microcycles (3, 4, 6, 7, 11, 14).

PRECAUTIONS FOR TRAINING TO FAILURE

Training to failure should not be performed repeatedly over long periods, due to the high potential for overtraining and overuse injuries (2, 15, 16). Athletes should be instructed to rack the resistance when they can longer maintain correct technique. For older adults and individuals who lift recreationally for the purpose of improving physical function, there is no reason to train to failure. Additionally, some individuals may have preexisting musculoskeletal injuries or cardiovascular conditions that might prohibit training to failure (15).

Baechle, Earle, and Wathen (2) recommended that athletes perform full RM sets with heavy loads 1 day per week. During the other days of the week, light or medium loads were recommended at a percentage of the RM value. Therefore, performing sets to failure should be varied, just as any other variable within a periodized program. An effective strategy might be to alternate between microcycles in which work sets are performed to failure at a lower weekly training frequency (e.g., each muscle group trained twice per week), with microcycles in which work sets are not performed to failure at a higher weekly training frequency (e.g., each muscle group trained 3 times per week).

Whether resistance exercises sets are performed to failure also depends on the type of equipment being utilized and the intent of the lifter. For example, a bodybuilder might utilize variable resistance machines to emphasize different muscle groups, with the intent to maximize muscular hypertrophy (4, 6, 7, 14). In such cases, the goal might be to reach failure on nearly every set (15). Conversely, a football player might utilize free weights to increase sports specificity, with the intent to maximize muscular power. In such cases, training to failure might be detrimental if the goal is to achieve maximal power output on every repetition (1, 2, 5, 13, 15).

RESEARCH ON TRAINING TO FAILURE

The need for training to failure is not universally accepted and few studies have directly addressed failure vs. nonfailure training with equated intensity, volume, and frequency. Two studies examined training with 1 set performed to failure vs. multiple sets not performed to failure and demonstrated that the latter approach was superior for increases in maximum strength and power (13, 16). However, greater increases in these characteristics were attributed to periodic variations in the volume and intensity; the failure variable was never directly examined or discussed. Research has clearly demonstrated the superiority of performing multiple sets vs. single sets for increases in maximal strength (1, 2). However, there is little direct evidence to decide conclusively whether or not multiple sets should be performed to failure.

Peterson, Rhea, and Alvar (9) analyzed a sample of studies from previously conducted meta-analyses (8, 10) and concluded that multiple sets not performed to failure were superior for maximal strength increases when controlling for intensity and frequency. However, this conclusion was short-sighted and misleading when considering that none of the studies included in either meta-analysis directly examined training to failure (8, 10). The fact that several studies involved lifting programs based on RMs suggests that subjects in these studies were training to failure (intentionally or at random), even when not reported as part of the overall data set (8, 10). In such cases, a study could have been classified as nonfailure, when in fact subjects were training to failure a large percentage of the time.

Therefore, the use of meta-analytic techniques to compare the effectiveness of failure vs. nonfailure sets should include relevant studies in order to make accurate conclusions. In reviewing the literature, 4 studies have directly examined the role of fatigue or training to failure on muscular adaptations, while equating for all other variables (3, 5, 11, 14). These studies will be presented in chronological order.

Rooney, Herbert, and Balnave (11) examined increases in dynamic and isometric strength of the elbow flexors resulting from failure vs. nonfailure training in untrained subjects. Following the pretests, subjects were matched and assigned to a no-rest group or a rest group. For 6 weeks, subjects in each group trained 3 times per week with a 6RM load that was progressively increased to keep the relative intensity the same. Training volume was equated between groups, because subjects in the no-rest group performed 1 set of 6 consecutive repetitions to failure, whereas subjects in the rest group performed 6 sets of 1 repetition not to failure with 30 seconds of rest between sets. When subjects in the no-rest group were unable to complete the prescribed number of repetitions, the supervising investigator provided minimal assistance.

Rooney et al. (11) demonstrated greater increases in dynamic and isometric strength for the no-rest group (7.0 and 6.6 kg) vs. the rest group (5.1 and 6.0 kg). The greater increases in strength for the no-rest group were attributed to higher levels of fatigue. A second experiment established that the no-rest protocol induced greater fatigue, measured with maximal isometric muscle actions immediately before and after lifting. The authors speculated that high-intensity fatiguing protocols bring about greater activation motor units than do high-intensity nonfatiguing protocols and that the degree of activation of motor units determines the magnitude of the strength training response.

Schott, McCully, and Rutherford (14) examined increases in quadriceps isometric strength and cross-sectional area resulting from short vs. long isometric muscle actions in untrained subjects. Following the pretests, subjects trained 3 times per week for 14 weeks. The right leg was trained using short, intermittent muscle actions (IC), whereas the left leg was trained using longer, continuous muscle actions (CC). The IC protocol involved 4 sets of 10 muscle actions lasting 3 seconds each, with a 2-second rest between each muscle action and a 2-minute rest between each set. The CC protocol involved 4 muscle actions lasting 30 seconds each, with a 1-minute rest between each muscle action. Therefore, the total volume of training for each protocol was equalized at 120 seconds. Muscle actions were conducted at 70% of the maximal isometric force, which was determined prior to each training session.

Schott et al. (14) demonstrated greater increases in quadriceps isometric strength for the CC protocol (24.9 kg) vs. the IC protocol (14.3 kg). Additionally, greater percentage increases in quadriceps cross-sectional area resulted from the CC protocol (10.1% upper three-quarters femur and 11.1% lower one-quarter femur) vs. the IC protocol (6.5% upper three-quarters femur and 4.3% lower one-quarter femur). The greater increases resulting from the CC protocol were attributed to higher levels of fatigue, consistent with greater changes in metabolites. A second experiment established that the CC protocol resulted in a greater drop in Ph and PCr and a greater rise in Pi and Pi:PCr ratio. The authors speculated that higher levels of fatigue may stimulate greater protein synthesis and release of insulin-like growth factor-1 (IGF-1).

Drinkwater et al. (3) examined the importance of training leading to repetition failure on 6RM bench press strength and the power output during a 40-kg bench throw in elite junior athletes. Following the pretests, subjects were matched and were assigned to 1 of 2 bench press training groups consisting of 4 sets of 6 repetitions to failure (RF group) or 8 sets of 3 repetitions not to failure (NF group). Both groups were equated for volume (24 total repetitions each workout) and relative intensity (85–105% 6RM), training 3 times per week for 6 weeks.

During each workout, the RF group needed assistance on at least 1 repetition, whereas the NF group was able to complete all repetitions without assistance (3). In a second experiment, bench throw power was used to measure the extent of fatigue elicited by each protocol. Subjects performed each protocol on separate days, and a fatigue index was calculated by comparing bench throw power before and after lifting.

Drinkwater et al. (3) demonstrated that the increase in 6RM strength experienced by the RF group (7.3 kg) was greater than that experienced by the NF group (3.6 kg). Additionally, greater increases in bench throw power were demonstrated by the RF group (40.8 W) vs. the NF group (25.0 W). Calculation of the fatigue index demonstrated that bench throw power following the 4 sets of 6 repetitions to failure was 15.9% lower than following the 8 sets of 3 repetitions not to failure. The authors speculated that the RF group experienced greater increases in strength and power by maximizing the number of active motor units leading to greater neural adaptations.

Izquierdo et al. (5) examined failure vs. nonfailure training on localized muscular endurance, strength, and power over 16 weeks in physically active men. The final 5 weeks of this study were designed to be a peaking period for maximal strength and power. Muscular testing and blood draws to determine basal hormonal concentrations were conducted before the initiation of training and at regular intervals throughout the study period.

Izquierdo et al. (5) demonstrated that the failure (RF) and nonfailure (NRF) groups experienced similar percentage increases in 1RM bench press (23 and 23%) and 1RM squat (22 and 23%) and power output of the arm (27 and 28%) and leg extensor muscles (26 and 29%). The RF group demonstrated larger increases in the maximal number of repetitions performed during the bench press. However, the RF group also demonstrated reductions in resting concentrations of IGF-1, whereas the NRF group demonstrated reductions in resting cortisol concentrations and an elevation in resting serum total testosterone concentration.

Overall, greater increases in muscular power were demonstrated by the NRF group, particularly during the 5-week peaking period, and greater increases in muscular endurance were demonstrated by the RF group (5). The reduction in IGF-1 for the RF group may have been an indicator of overtraining. The difference between these results and those reported in other studies might be accounted for by the length of the study periods. For example, 2 of the previous studies that demonstrated the superiority of training to failure were conducted only for 6 weeks (3, 11). This may indicate that training to failure can be advantageous, but only when prescribed sparingly and not for more than 6 weeks at a time.

Practical Applications

Planned variation in training variables is the key for optimal increases in muscular characteristics (1, 2). One training issue that has not been frequently discussed or examined under controlled research conditions is whether resistance exercise sets should be performed to failure (3, 5–7, 9, 11, 14, 15). Training to failure might be most beneficial when programs are structured for increases in strength and hypertrophy (3, 7, 11, 14). Because muscular hypertrophy is a major contributor to long-term increases in maximal strength, advanced lifters should consider training to failure occasionally.

Training to failure might provide the extra stimulus needed for advanced lifters to break through plateaus when incorporated periodically into short-term microcycles (3, 15). Research has demonstrated that during 6-week cycles, training to failure resulted in superior increases in strength and hypertrophy in both untrained subjects and elite athletes (3, 11, 14). These adaptations were attributed to greater activation of motor units and secretion of growth promoting hormones.

However, training to failure should not be practiced repeatedly over long periods due the potential for decreases in growth-promoting hormones and increases in overuse injuries (5, 15, 16). An effective strategy might be to alternate microcycles in which failure is reached on most sets with microcycles in which sets are performed according to repetition zones or RM percentages that do not require failure. For older adults and individuals who lift recreationally for the purpose of improving physical function, there is no reason to train to failure. Therefore, the training status and goals of the lifter should guide the decision-making process on this issue.

Recommendations for Future Research

Future research should continue to examine failure vs. nonfailure training on muscular power. Two key factors that determine the development of this characteristic are force production and the rate of force development. Therefore, future research should explore the effects of failure vs. nonfailure training on each of these factors. Based on the existing research, training to failure might be advantageous during short-term strength phases in which heavy loads are lifted for the purpose of increasing force production (3, 11, 14). Conversely, not training to failure might be advantageous during peaking phases in which explosive resistance exercises are performed for the purpose of increasing the rate of force development (5).

Future research should continue to examine the effect of failure vs. nonfailure training on muscular hypertrophy. A key factor that determines the development of this characteristic is the secretion of growth-promoting hormones. Linnamo et al. (7) demonstrated higher acute levels of growth hormone and testosterone following workouts in which subjects trained to failure. Conversely, Izquierdo et al. (5) demonstrated reductions in resting IGF-1 concentrations in subjects who trained to failure repeatedly over 16 weeks. Based on these inconsistent outcomes, future research should continue to explore the effects of failure vs. nonfailure training on both acute and chronic hormonal responses.

Future research should continue to examine the effect of failure vs. nonfailure training on localized muscular endurance. Because this characteristic is defined as the ability to maintain submaximal muscle actions, training to failure might be advantageous (1, 2). Izquierdo et al. (5) demonstrated greater increases in bench press endurance when subjects trained to failure. However, the examination of additional exercises when performed in a circuit vs. a traditional straight-set approach would be useful. Future research also should examine the potential mechanisms by which training to failure might enhance recovery ability and allow for greater resistance to fatigue.

REFERENCES

1. AMERICAN COLLEGE OF SPORTS MEDICINE. Progression models in resistance training for healthy adults. *Med. Sci. Sports Exerc.* 34:364–380. 2002.
2. BAECHLE, T.R., R.W. EARLE, AND D. WATHEN. Resistance training. In: *Essentials of Strength Training and Conditioning.* T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 395–425.
3. DRINKWATER, E.J., T.W. LAWTON, R.P. LINDSELL, D.B. PYNE, P.H. HUNT, AND M.J. MCKENNA. Training leading to repetition failure enhances bench press strength increases in elite junior athletes. *J Strength. Cond. Res.* 19:382–388. 2005.
4. GOTO, K., M. NAGASAWA, O. YANAGISAWA, T. KIZUKA, N. ISHII, AND K. TAKAMATSU. Muscular adaptations to combinations of high and low intensity resistance exercises. *J. Strength Cond. Res.* 18:730–737. 2004.
5. IZQUIERDO, M., J. IBANEZ, J.J. GONZALEZ-BADILLO, K. HÄKKINEN, N.A. RATAMESS, W.J. KRAEMER, D.N. FRENCH, J. ESLAVA, A. ALTADILL, X. ASIAIN, AND E.M. GOROSTIAGA. Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength and muscle power increases. *J. Appl. Physiol.* 100:1647–1656. 2006..
6. JACOBSON, B. Reach failure to gain success. *Natl. Strength Coaches Assoc. J.* 3(2):24–25. 1981.
7. LINNAMO, V., A. PAKARINEN, P.V. KOMI, W.J. KRAEMER, AND K. HÄKKINEN. Acute hormonal responses to submaximal and maximal heavy resistance and explosive exercise in men and women. *J. Strength Cond. Res.* 19:566–571. 2005.
8. PETERSON, M.D., M.R. RHEA, AND B.A. ALVAR. Maximizing strength development in athletes: A meta-analysis to determine the dose-response relationship. *J. Strength Cond. Res.* 18:377–382. 2004.
9. PETERSON, M.D., M.R. RHEA, AND B.A. ALVAR. Applications of the dose-response for muscular strength development: A review of meta-analytic efficacy and reliability for designing training prescription. *J. Strength Cond. Res.* 19:950–958. 2005.
10. RHEA, M.R., B.A. ALVAR, L.N. BURKETT, AND S.D. BALL. A meta-analysis to determine the dose response for strength development. *Med. Sci. Sports Exerc.* 35:456–464. 2003.
11. ROONEY, K.J., R.D. HERBERT, AND R.J. BALNAVE. Fatigue contributes to the strength training stimulus. *Med. Sci. Sports Exerc.* 26:1160–1164. 1994.
12. SALE, D.G. Influence of exercise and training on motor unit activation. *Exerc. Sport Sci. Rev.* 15:95–151. 1987.
13. SANBORN, K., R. BOROS, J. HRUBY, B. SCHILLING, H.S. O'BRYANT, R.L. JOHNSON, T. HOKE, M.E. STONE, AND M.H. STONE. Short-term performance effects of weight training with multiple sets not to failure vs. a single set to failure in women. *J. Strength Cond. Res.* 14:328–331. 2000.
14. SCHOTT, J., K. MCCULLY, AND O.M. RUTHERFORD. The role of metabolites in strength training: Short versus long isometric contractions. *Eur. J. Appl. Physiol.* 71:337–341. 1995.
15. STONE, M.H., J. CHANDLER, M.S. CONLEY, J.B. KRAMER, AND M.E. STONE. Training to muscular failure: Is it necessary? *Strength Cond.* 18(3):44–48. 1996.
16. STOWERS, T., J. MCMILLAN, D. SCALA, V. DAVIS, G.D. WILSON, AND M.H. STONE. The short-term effects of three different strength-power training methods. *NSCA J.* 5(3):24–27. 1983.

Address correspondence to Dr. Jeffrey Willardson, jmwillardson@eiu.edu.