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Effect of Short-Term Failure Versus Nonfailure Training on Lower Body Muscular Endurance

Jeffrey M. Willardson, John Emmett, Jon A. Oliver, and Eadric Bressel

Purpose: This study compared failure versus nonfailure training with equated intensity and volume on lower body muscular endurance in trained men. ***Methods:*** Each subject performed one lower body workout per week for 6 weeks; the *Failure group* performed 3 sets of the squat, leg curl, and leg extension exercises to the point of voluntary exhaustion, while the *Nonfailure group* performed 4 sets for each of these exercises, but with a submaximal number of repetitions that did not allow failure to occur on any set. All subjects performed a pre- and postintervention muscular endurance test that involved 3 sets each for the squat, leg curl, and leg extension exercises. Blood lactate concentration (BL) was assessed before, and at 5 and 10 minutes following the test. Heart rate (HR) was assessed before the test, following the last set of each exercise, and for 10 minutes following the test. ***Results:*** Both groups demonstrated significant increases in total work ($P < .0001$) for the postintervention test, with no significant differences between the groups ($P = .882$). When comparing the pre- and postintervention tests, BL and HR were not significantly different at any time point ($P > .05$). ***Conclusions:*** These results indicate that when intensity and volume are equated, failure or nonfailure training results in similar gains in lower body muscular endurance. Therefore, when assessed over relatively short training cycles, the total volume of training might be more important versus whether sets are performed to failure for muscular endurance-related adaptations.

Keywords: fatigue, work, lactate, heart rate, squat, resistance training

Resistance training has grown tremendously in popularity and is considered beneficial for maintenance of physical function throughout the lifespan.[1,2] Resistance exercise programs can be structured to emphasize different muscular characteristics. There are four generally acknowledged and trainable muscular characteristics, and these include muscular endurance, hypertrophy, strength, and power.[1,2] These are not mutually exclusive characteristics, and training intended to

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develop one characteristic may also result in some development of others. However, training variables can be structured to emphasize one over the others.

Training variables that are common in resistance exercise prescription include mode (ie, free weights or machines), intensity level (ie, percentage of a 1 repetition maximum), number of sets, number of repetitions per set, velocity of repetitions, and rest intervals between sets and exercises. There is an inverse association between the intensity level or amount of resistance and the maximal number of repetitions that can be completed during a set; as the amount of resistance increases, the muscles fatigue at a faster rate, resulting in less repetitions being completed.[1,2]

Reaching a certain level of fatigue is anecdotally accepted as being necessary for adaptations to occur in muscular characteristics.[3–5] However, there is a lack of research to determine whether less or more fatigue is optimal. During the early 1970s a marketing scheme connected with the sale of Nautilus equipment popularized the concept of performing a single set to failure. However, power lifters and bodybuilders that followed resistance training programs based on repetition maximums (RM) were probably training to failure (intentionally or at random) before this time period. Previous studies that examined this issue have produced inconsistent results depending on the type of muscle action, the muscular characteristic being trained, the length of the study period, the training status of the subjects, and the total volume of training performed.[6–13]

Rooney et al.[10] compared failure versus nonfailure training programs in untrained subjects over 6 weeks. Greater increases in isometric and dynamic strength of the elbow flexors were demonstrated consequent to the failure training program. Likewise, Schott et al[12] compared programs that involved less fatiguing short isometric muscle actions versus more fatiguing long isometric muscle actions in untrained subjects over 14 weeks. Greater increases in isometric strength and cross-sectional area of the quadriceps was demonstrated for the more fatiguing long isometric training program. The authors of each of these studies hypothesized that training to failure, or in such a manner to elicit higher levels of fatigue, may result in greater adaptations due to greater activation of motor units and secretion of growth-promoting hormones.

In contrast, Izquierdo et al.[8] examined failure versus nonfailure training programs on localized muscular endurance, strength, and power over 11 weeks in trained subjects. Although there were no differences between training programs in bench press or squat strength gains; greater increases in squat power were demonstrated for the nonfailure program. Collectively, these studies were primarily focused on strength and power adaptations resulting from failure versus nonfailure training approaches.[8,10,12] Therefore, more research is necessary to determine changes in muscular endurance consequent to each of these training approaches.

Izquierdo et al.[8] demonstrated greater bench press muscular endurance in subjects that trained to failure; however, muscular endurance was assessed with a single set of repetitions performed to exhaustion at 75% of 1-RM. Since muscular endurance has been defined as the ability to continue performing submaximal muscle actions, a better assessment of muscular endurance might consist of multiple sets and multiple exercises performed in a circuit with short rest intervals between sets.[14,16]

Furthermore, Izquierdo et al.[8] assessed muscular endurance performance with the total repetitions performed; this approach may not account for differences between subjects in the range of motion and total work performed. Furthermore, several previous studies have been cross-sectional and did not evaluate changes in physiological responses (ie, heart rate, blood lactate concentration) consequent to failure versus nonfailure training.[14–18] Data on these variables may lend insight into how to structure a muscular endurance training program for maximal adaptations.

Therefore, the purposes of the current study were to compare failure versus nonfailure training programs on lower body muscular endurance using a circuit approach and to compare changes in heart rate and blood lactate concentration in trained men consequent to failure versus nonfailure training. Based on the results of previous studies (that demonstrated the superiority of failure training for increasing muscular strength[7,10]), we hypothesized that the failure approach would result in greater increases in lower body muscular endurance.

Methods

Experimental Design

Muscular endurance was assessed pre- and postintervention by calculating the total concentric work performed during a lower body circuit. The total concentric work performed for each exercise in the testing circuit was computed as the product of the weight lifted in the vertical direction and vertical distance moved per repetition times the number of repetitions (Work = weight × distance). The weight lifted included the bar, the iron plates, and the subject's body segments. The weight and center of gravity of each body segment was estimated using cadaveric data collected by Dempster[20] and procedures outlined by Robertson.[21]

The vertical distance moved by each weight's center of gravity was measured from sagittal plane video images sampled at 60 Hz. The video camcorder (Panasonic GS55; Matsushita Electric Corp., Secaucus, NJ) was positioned approximately 4 m from the object points and at a height of .5 m from the floor. Using a motion analysis system (Peak Motus; Vicon, Centennial, CO) object points of interest were digitized, and then filtered coordinate data from the average of three lifts were used to compute the linear distances moved by each weight's center of gravity.

Following completion of the pre intervention test, subjects were matched based on the total concentric work performed, (while also considering the loads used and the repetitions performed), and then randomly assigned to a *failure* (F; N = 10) or a *nonfailure* (NF; N = 10) training group (see Table 1). The workouts followed a nonlinear periodized approach, with the intensity of each workout varying between 60% and 115% of the previously established 15-RM (see Table 2). During each workout, subjects assigned to the F group performed 3 sets of 13 to 15 repetitions of the squat, leg curl, and leg extension to the point of voluntary exhaustion, whereas subjects assigned to the NF group performed 4 sets of 10 to 12 repetitions, and did not reach failure on any set. The additional set performed for each exercise by the NF group allowed for the volume to be equated between

Table 1 Comparison Demographical Characteristics (Mean ± SD)

	Failure Group (N = 10)		Non-Failure Group (N = 10)		
Variable	**Mean**	**SD**	**Mean**	**SD**	***P***
Age	21.60	1.84	21.10	1.29	.491
Height	178.05	9.39	181.10	6.34	.408
Body Mass	83.27	9.66	90.81	16.95	.241
Squat	120.45	20.13	105.23	19.11	.100
Leg Curl	63.64	9.34	68.18	9.28	.289
Leg Ext.	96.59	11.99	94.77	14.01	.759

Age is reported in years (y), height is reported in centimeters (cm), body mass is reported in kilograms (kg), and the squat, leg curl, and leg extension are reported in kg. The load listed for the squat, leg curl, and leg extension represents a 15-RM.

groups. The Microsoft Excel program was used to equate the volume in kilograms for each workout. This was computed as the sum of the load lifted for each exercise set times the number of repetitions performed for each exercise set (Volume = load × repetitions; see Table 3).

Subjects in each group performed one lower body workout per week for 6 weeks under the direct supervision of the principal investigator. Since the training programs were designed to increase muscular endurance, performing the 3 exercises in a circuit one day per week was considered superior to splitting up the exercises over two or three days per week.[2] The researchers also felt that the workouts should be as specific as possible to how muscular endurance would be evaluated during the pre- and postintervention tests. Furthermore, pilot testing indicated that subjects were unable to recover sufficiently to perform more than one lower body workout per week; this was especially true for the failure group.

Subjects

Twenty men volunteered to participate in this 11-week study (see Table 2). All subjects were recreational lifters and had a minimum of 4 years resistance training experience. The training program instituted for the current study was similar to previous training programs practiced by the subjects in that the squat was typically performed before the leg curl and the leg extension. Furthermore, these exercises were typically performed once per week with multiple sets of 10 to 15 repetitions per set. However, a key difference between the training protocol and their previous style of training was the utilization of 1-minute rest intervals between sets; they had previously used 3- to 4-minute rest intervals. Furthermore, all of the subjects lifted for health and aesthetic reasons and were not accustomed to lifting with sufficient intensity to elicit failure or close to failure in 10 to 15 repetitions. None of the subjects had previously exerted themselves at level of effort required for this study.

To qualify for inclusion, all subjects were initially screened using the Physical Activity Readiness Questionnaire (PAR-Q) and determined to be healthy.

Table 2 Eleven-Week Failure Versus Nonfailure Study

Week(s)	Protocol
1–3	Pretesting Order (5-min rest between assessments): Barbell Squat 15-RM Assessment Nautilus Leg Extension 15-RM Assessment Nautilus Leg Curl 15-RM Assessment
4	Endurance Test 1 (see description in *Methods* and Table 2)
	Randomized Group Assignment
5	Squat 105, 90, (90 NF), 80 Leg Curl 85, 70, (70 NF), 60 Leg Extension 85, 70, (70 NF), 60
6	Squat 105, 95, (95 NF), 80 Leg Curl 85, 75, (75 NF), 60 Leg Extension 85, 75, (75 NF), 60
7	Squat 110, 95, (95 NF), 85 Leg Curl 90, 75, (75 NF), 65 Leg Extension 90, 75, (75 NF), 65
8	Squat 110, 100, (100 NF), 85 Leg Curl 90, 80, (80 NF), 65 Leg Extension 90, 80, (80 NF), 65
9	Squat 115, 100, (100 NF), 90 Leg Curl 95, 80, (80 NF), 70 Leg Extension 95, 80, (80 NF), 70
10	Squat 115, 105, (105 NF), 90 Leg Curl 95, 85, (85 NF), 70 Leg Extension 95, 85, (85 NF), 70
11	Endurance Test 2 (see description in *Methods* and Table 3)

The intensity of each set is listed by the exercise. The intensity is expressed as a percentage of the 15-RM load. During all workouts, subjects in each group rested 1 minute between sets and 2 minutes between exercises.

Before data collection, the institutional review board committee approved the experimental protocol, and the subjects were required to sign a consent form in accordance with human subject regulations. Subjects were permitted to continue with their usual upper body strength training on different days throughout the intervention. However, subjects were restricted from performing any other lower body resistance exercises (eg, leg press, lunge, deadlift) that might confound the results.

Independent Variables

All squat 15-RM tests and workout sets were performed while standing inside a lifting cage. The safety pins were adjusted within the lifting cage to allow each subject to descend to the point at which the tops of the thighs were parallel to the floor. During the 15-RM testing, if the subject was unable to complete a repetition, they were instructed to set the weight on the safety pins. All leg curl and leg

Table 3 Weekly Workout Results (Mean ± SD)

	Failure Group				Nonfailure Group			
Week	Volume	SD	Repetitions per Set	SD	Volume	SD	Repetitions per Set	SD
5	10,402.50	1,444.63	15.51*	2.09	9597.73	1168.80	11.57	1.31
6	10,064.77	2,294.81	15.56*	2.08	9980.23	1000.17	11.62	1.04
7	10,611.59	1,699.00	14.70*	2.24	10319.55	1268.63	11.68	1.60
8	10,937.27	1,890.48	15.19*	2.58	10650.68	1316.13	11.79	1.56
9	10,864.77	2,057.98	14.07*	2.44	10698.86	1446.54	11.49	1.67
10	10,568.18	1,663.49	13.94*	2.56	10059.09	1057.17	10.93	1.70

*Repetitions per set significantly different between groups ($P < .01$). The repetitions per set represent the mean for all exercise sets during a workout. Volume is expressed in kg and was calculated as the sum of the load lifted for each exercise set times the number of repetitions performed for each exercise set (Volume = load × repetitions).

extension 15-RM tests and workout sets were performed using Nautilus equipment (Vancouver, Washington). The leg curl was performed in the prone position and the leg extension was performed in the seated position. Before performing each 15-RM test or workout set, the knee joint was aligned with the axis of the resistance arm. The pad at the end of the resistance arm was adjusted a little above the feet.

The specific adjustments for each subject were recorded for consistency throughout the study. During each repetition of the leg curl exercise, hamstrings strength was used to raise the resistance arm to a position at which the knee joint made a 90 degree angle, before lowering the resistance arm back to the starting point. During each repetition of the leg extension exercise, quadriceps strength was used to raise the resistance arm to a position at which the knee joint was nearly locked, before lowering the resistance arm back to the starting point.

All of the 15-RM assessments were based on previously published procedures.[19] Briefly, subjects began by performing two warm-up sets at 50% and 60% of the resistance they perceived to be their 15-RM. The resistance was then raised to the 15-RM, and subjects were instructed to perform as many repetitions as possible to the point of reaching voluntary exhaustion. If subjects were able to perform more than 15 repetitions, the resistance was raised approximately 10 kg, and another 15-RM was attempted after a 5-minute rest period. To improve the accuracy of the 15-RM testing, no more than two repetition maximum attempts were allowed for each exercise during each of the pretesting sessions. The results from the last two pretesting sessions were used to calculate reliability (see Results).

Dependent Variables

Muscular endurance was assessed pre- and postintervention with a circuit that included 3 sets each of the squat, leg curl, and leg extension exercises. Each set was performed to the point of voluntary exhaustion and the intensity of each set was based on a percentage of the previously established 15-RM load. The intensity was lowered 10% for each consecutive set (see Table 4). Pilot testing indicated that lowering the resistance allowed for the maintenance of repetitions and stimulated relatively high heart rates (HR) and blood lactate concentrations (BL). This strategy was consistent with similar studies that evaluated muscular endurance performance.[14–18]

Subjects rested 1 minute between sets and 2 minutes between exercises. This allowed for sufficient time for movement and calibration of the video camcorder before each exercise. Rest intervals between sets and exercises were timed using a hand-held stop watch. The same loads were used for the pre- and posttests to assess changes in muscular endurance consequent to the failure versus nonfailure training programs.

HR data were collected using a wireless Polar HR monitor (Lake Success, NY). HR was assessed in beats per minute before the test, immediately following completion of the third set of each exercise, and for 10 minutes following the test. BL concentrations were measured in millimoles per liter using the Accutrend Lactate analyzer (Mannheim, Germany). Using a sterile lancet, a 20- to 25-μL blood sample was taken from the finger using a 32-μL heparinized capillary tube. Blood samples were dispensed with an applicator onto a lactate strip inserted into the analyzer. The analyzer was calibrated according to the manufacturer's specifications after every 25 measurements. BL concentrations were assessed before the muscular endurance test, and at 5 and 10 minutes following completion of the test.

Statistical Analysis

The reliability of the 15-RM tests for the squat, leg curl, and leg extension were assessed using Cronbach's alpha for the second and third assessments. Independent *t* tests were used to compare demographical characteristics and 15-RM loads between groups. A series of two (group: F vs. NF) × two (time: pre muscular endurance test vs. post muscular endurance test) repeated ANOVAs were used to compare differences in the total concentric work for the entire circuit and the work performed for each exercise pre- and postintervention. A two (group: F vs. NF) × six (total BL assessments that occurred during the pre- and postintervention tests combined) repeated ANOVA was used to compare differences in BL concentrations pre- and postintervention. A two (group: F vs. NF) × twenty-six (total HR assessments that occurred during the pre- and postintervention tests combined) repeated ANOVA was used to compare differences in HR pre- and postintervention.

A two (group: F vs. NF) × six (volume performed during each week of the six week intervention) repeated ANOVA was used to compare differences in training volume during each week of the intervention. A two (group: F vs. NF) × six (repetitions per set during each week of the 6-week intervention) repeated ANOVA was used to compare differences in the repetitions per set during each week of the training period. An alpha level of .05 was used to determine significance for all comparisons. In the case of significance, follow-up comparisons were made using the Bonferroni adjustment. Statistical analysis was completed using SPSS version 14.0 (SPSS Inc., Chicago, IL).

Table 4 Endurance Test Protocol and Results (Mean ± SD)

Protocol:

- Pre Blood Lactate
- 2 Squat Warm-up Sets at 50% and 60% of the 15-RM load
- Squat 100, 90, 80 (1 min of rest between sets)
- HR recorded immediately following last set
- 2 min of rest
- Leg Curl 80, 70, 60 (1 min of rest between sets)
- HR recorded immediately following last set
- 2 min of rest
- Leg Ext. 80, 70, 60 (1 min of rest between sets)
- HR recorded immediately following last set and every minute thereafter for 10 min
- Blood lactate measured at 5 min and 10 min postexercise

Mean Work	Failure Group	SD	Non-Failure Group	SD
Endurance Test 1	47,114.41	10,214.30	46,221.80	8,264.62
Squat	30,657.52	6,178.18	29,733.29	5,862.46
Leg Curl	9,706.78	3,729.57	9,687.96	1,785.50
Leg Ext.	6,750.11	2,748.49	6,800.54	1,904.64
Endurance Test 2	58,265.31	16,059.75	60,639.76	11,617.62
Squat	38,579.04	10,539.43	41,326.88	7,308.91
Leg Curl	11,447.29	3,858.93	11,512.47	2,911.76
Leg Ext.	8,238.98	3,153.56	7,800.42	2,393.33

Mean work is expressed in joules and was calculated for the concentric phase only.

Results

The Cronbach's alpha values indicated high reliability of the 15-RM tests (α > .90, all exercises). There were no significant differences between groups for any demographical variable or for the 15-RM on any exercise (see Table 1). Both groups demonstrated significant increases in total work (P = .0001) for the postintervention test, with no significant differences between the groups (P = .882; see Table 4). When analyzing each exercise individually, both groups demonstrated significant increases on the work performed for the squat exercise (P = .0001), with no significant differences between the groups (P = .773). Both groups demonstrated significant increases on the work performed for the leg curl exercise (P = .0001), with no significant differences between the groups (P = .987). Both groups demonstrated significant increases on the work performed or the leg extension exercise (P = .023), with no significant differences between the groups (P = .855). There were no significant group × time interactions for any of these statistical analyses.

Both groups experienced significant elevations in BL concentrations with no significant differences between the groups (P = .155; see Figure 1). When comparing the pre-and postintervention tests, BL concentrations were not significantly different at any time point (P > .05). The HR values elicited by the squat were significantly higher than the leg curl and the leg extension, with no significant differences between the groups (P = .688). When comparing the pre- and postintervention tests, HR was not significantly different at any time point (P > .05; see Figure 2).

For both groups, training volume peaked during weeks 8 and 9 and was significantly greater than week 5. There were no significant differences in weekly training volume between the groups (P = .585). However, as expected, the repetitions per set during each week were significantly different between the groups (see Table 3).

Discussion

The key finding from this study was the similar increase in lower body muscular endurance in the F and NF groups. Therefore, the initial hypothesis was rejected. This was an important finding, in that individuals can choose which approach best suites them, and the muscular endurance improvements will be approximately equal. The nonfailure approach would involve performing an additional set of each exercise (ie, 4 sets versus 3 sets), while performing a submaximal number of repetitions that does not lead to failure on any set.

The nonfailure approach might be advantageous for individuals who do not possess the psychological fortitude to train to failure or have health issues (eg, high blood pressure) that could be contraindicated by such an approach. The nonfailure approach may also reduce the risk of injury that could be greater if repetitions are continued to the point of voluntary exhaustion.

Conversely, the failure approach might be advantageous for individuals with busy schedules who desire a more efficient approach. In such cases, maximal repetitions should be performed on every set. Healthy young athletes during preseason training cycles might consider the failure approach to allow less time in the weight room and more time for practicing sports skills and game strategies.

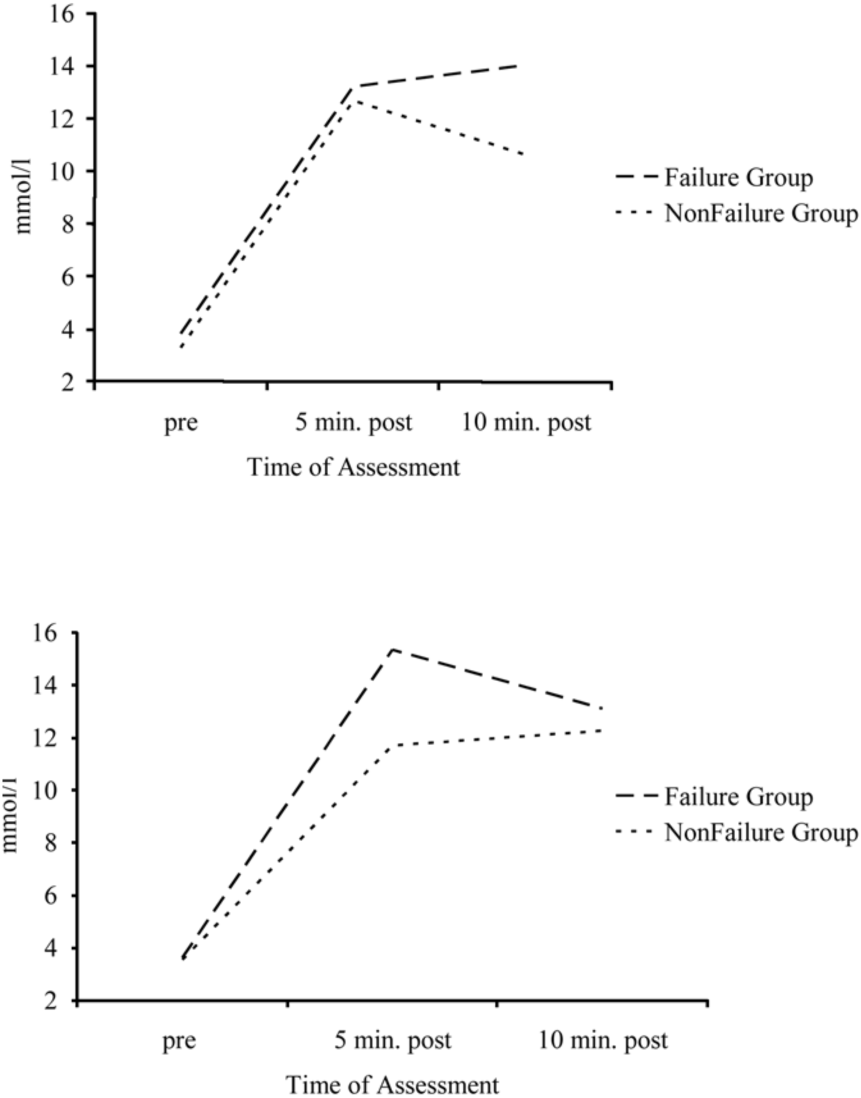

Figure 1 — Blood lactate concentration pre- (top) and postintervention (bottom).

The results of the current study suggest that the total volume of training might be more important for muscular endurance adaptations versus whether workout sets are performed to failure. This makes sense, when considering that the definition of muscular endurance is the ability to continue performing submaximal muscle actions, and not the ability to reach failure. Although reaching failure might be an inevitable consequence when testing for localized muscular endurance, this does not indicate that reaching failure is essential when training for

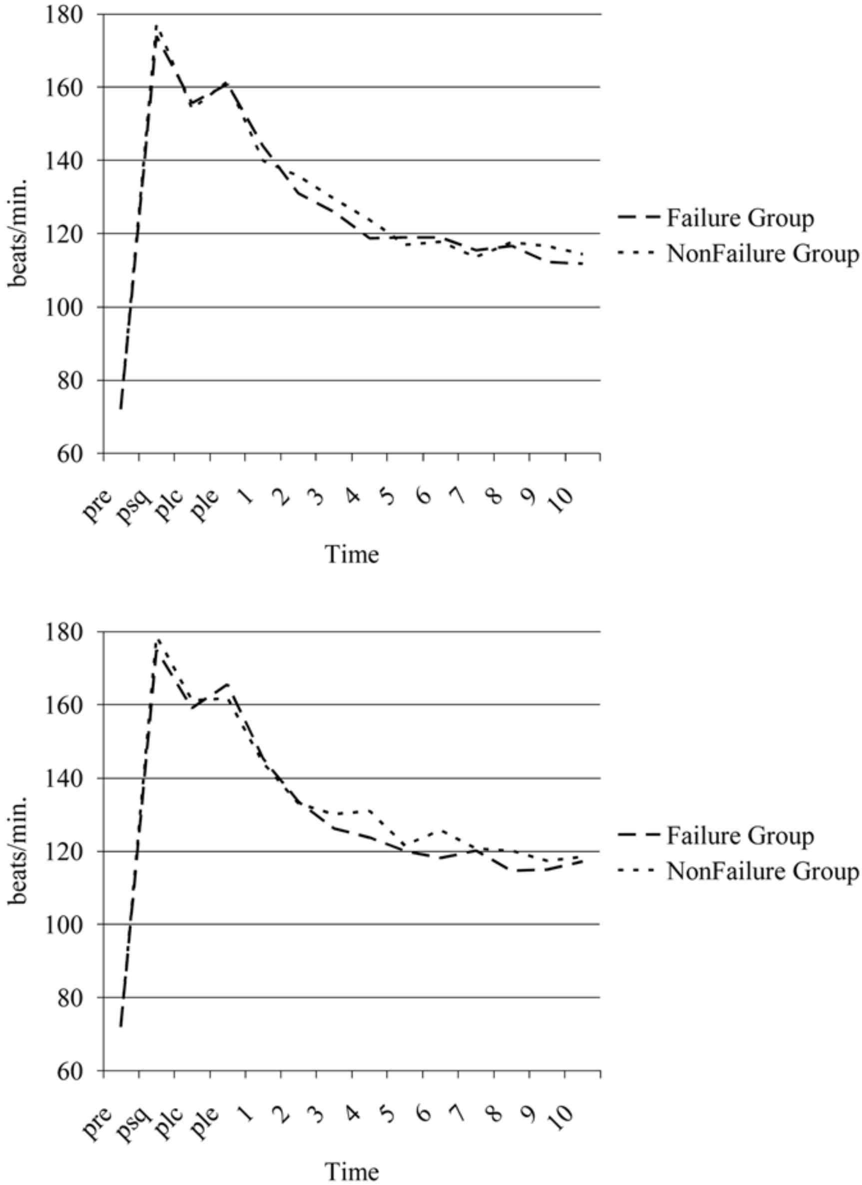

Figure 2 — Heart rate pre- (top) and postintervention (bottom). *Note.* pre = pretest heart rate; psq = post squat heart rate; plc = post leg curl heart rate; ple = post leg extension heart rate.

localized muscular endurance. Therefore, reaching failure may not be the most important priority, as long as the repetitions per set are maintained within the range conducive to muscular endurance development.

Previous studies have demonstrated training that leads to greater fatigue or training that leads to failure resulted in greater increases in muscular strength and power.[7,10] These studies used one resistance exercise that involved muscles of the upper body (eg, bench press, barbell curl). However, few studies have examined changes in muscular endurance consequent to failure versus nonfailure training protocols that used resistance exercises that involved muscles of the lower body.

Izquierdo et al[8] examined changes in bench press and half squat muscular endurance consequent to failure versus nonfailure training over 16 weeks. Muscular endurance for each of these exercises was assessed preintervention and at weeks 6, 11, and 16 (postintervention) with a single set of repetitions performed to failure at 75% of 1-RM. The authors found significant differences favoring the failure group in bench press muscular endurance at weeks 6 and 11. However, there were no differences between groups in half-squat muscular endurance at any time point.

When these results are considered collectively with those of the current study, the muscles of the upper body appear to be more responsive when sets are performed to failure versus the muscles of the lower body. Behm et al[24] suggested that the larger muscle mass of the lower body may be harder to achieve full activation in, even at maximal effort. This would make a substantial difference to the effects of failure training on the upper body versus the lower body if the muscle activation hypothesis as suggested by Rooney et al and Drinkwater et al is true.[7,10]

In prior studies, HR and BL concentrations have been used to compare the physiological responses to different resistance exercises or to compare individuals from different training backgrounds.[14–18] These studies indicated that the highest HR and BL concentrations resulted from lower intensities (ie, 40% to 60% 1-RM), performed for higher repetitions (ie, 10 to 15), and shorter rest periods between sets (ie, 30 s to 1 minute). Furthermore, the highest responses were demonstrated in individuals with training backgrounds that matched this style of lifting over long periods of time.

HR and BL responses were compared in trained and untrained lifters during a progressive squat workout that consisted of sets of 10 repetitions with 2.5 minutes rest between sets.[17] The subjects started with a 50-kg barbell, and the mass was raised by 12.5 kg per set until reaching voluntary exhaustion. The key finding was that the trained lifters performed more total work, and had significantly higher HR and BL concentrations at exhaustion versus the untrained lifters. However, the trained lifters demonstrated lower HR and BL concentrations at a given bar mass versus the untrained lifters.

In contrast, the current study compared groups of individuals with similar training backgrounds. A key finding was that both groups' demonstrated similar HR and BL responses during the postintervention test, despite performing greater total work (see Figures 1 and 2). These results demonstrated that the failure and nonfailure training approaches were equally effective in developing adaptations that allowed for greater fatigue resistance.

Although not assessed in the current study, these adaptations may have included increases in mitochondrial and capillary density, which may have allowed for greater energy production via oxidative processes, thus delaying proton accumulation, and the ensuing metabolic acidosis and eventual exhaustion.[18,22,23] Other potential adaptations may have included development of the fast glycolytic energy system, with higher activities of anaerobic enzymes (eg, phosphorylase, phosphofructokinase, and lactate dehydrogenase), and an increased the ability to buffer pH disturbances.[17]

Kraemer et al[16] demonstrated greater fatigue resistance in bodybuilders versus power lifters when completing a 10-station resistance exercise circuit. Similar to the current study, three consecutive sets of each exercise were performed with a 10-RM load that was progressively lowered to allow for 10 repetitions per set. Subjects rested 10 s between sets, and 30 to 60 s between exercises. The key finding was that the bodybuilders were able to sustain a significantly higher mean percentage of their 1-RM during performance of the squat and bench press sets.

Although bodybuilders train for muscular hypertrophy, Kraemer et al[16] demonstrated that this population also possessed greater muscular endurance in terms of the ability to continue performing repetitions with a higher relative load. Similar to the current study, bodybuilders typically use relatively short rest intervals (ie, 30 to 90 s between sets) and high repetition ranges (ie, 10 to 15 repetitions per set). Therefore, workouts performed in this manner can be expected to develop greater muscular endurance over time, even if the primary training goal might be muscular hypertrophy.

Practical Applications

Fitness trainers can use this information when designing lower body resistance exercise programs for improved muscular endurance in athletes over short training cycles. For example, the findings of this study would apply to trained distance runners during in-season training cycles when resistance exercises might be performed once per week. Further research is necessary to determine muscular endurance adaptations over longer training cycles or when training is conducted with greater frequency. From a broader perspective, a periodized approach might be ideal by dividing training into phases in which less sets are performed to failure (ie, 3 sets per exercise), with phases in which more sets are performed short of reaching failure (ie, 4 sets per exercise). This approach may allow for maximal adaptations to occur, while lowering the risk of overtraining associated with training to failure too frequently.[4]

Conclusion

The issue of whether training to failure is necessary has received little research attention, particularly with regard to increasing muscular endurance. Anecdotally, reaching a certain level of fatigue seems necessary, especially when training for muscular endurance. However, the current study demonstrated that failure and nonfailure training resulted in approximately equal changes in muscular endurance.

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