Journal of Strength and Conditioning Research, 2007, 21(4), 1320–1324

Research Note

EFFECTS OF SHORT VS. LONG REST PERIOD BETWEEN SETS ON ELBOW-FLEXOR MUSCULAR ENDURANCE DURING RESISTANCE TRAINING TO FAILURE

DAVID GARCÍA-LÓPEZ,[1] JOSÉ A. DE PAZ,[2] ERNESTO MONEO,[2] RODRIGO JIMÉNEZ-JIMÉNEZ,[2] GUILHERME BRESCIANI,[2] AND MIKEL IZQUIERDO[3]

[1]Faculty of Health Sciences, European University Miguel de Cervantes, Valladolid, Spain; [2]Department of Physiology, University of León, León, Spain; [3]Studies, Research and Sport Medicine Center, Government of Navarra, Navarra, Spain.

ABSTRACT. García-López, D., J.A. de Paz, E. Moneo, R. Jiménez-Jiménez, G. Bresciani, and M. Izquierdo. Effects of short vs. long rest period between sets on elbow-flexor muscular endurance during resistance training to failure. *J. Strength Cond. Res. 21(4):1320–1324. 2007.*—This study aimed to examine short-term resistance training effects of resting period length between sets on maximal number of repetitions and mean velocity over a moderate-intensity (60% of the maximum voluntary isometric contraction [MVIC]) set to failure on elbow-flexor muscles. The MVIC and surface electromyographic activity (sEMG) were also measured. Twenty-one untrained subjects were divided into 3 groups: short rest between sets (1 minute; SR), long rest between sets (4 minutes; LR), and nontraining control group (CG). The SR and LR performed 3 sets to failure in an arm-curl machine, 2 days per week for 5 weeks, with moderate loads (60–75% of the MVIC). The LR completed a significantly higher (31.6%, $p < 0.05$) total training volume than the SR. Both training groups enhanced the maximal number of repetitions to failure, with no significant differences in the magnitude of gains. The posttraining average velocity achieved by the SR at 40, 50, 60, 70, 80, and 90% of the total number of repetitions completed was significantly higher ($p < 0.05$) than the corresponding average velocity achieved on pretraining conditions, whereas no significant differences were observed in the LR. No significant changes in the MVIC or sEMG were observed in any group. We conclude that short-term elbow-flexor resistance training to failure, allowing 1 or 4 minutes of rest between sets, induces similar gains concerning local muscular endurance. Nevertheless, only the SR training approach reduced the rate of decline in the average repetition velocity during a set to failure. This can be of some importance in sport modalities in which not only the maximal number of repetitions (e.g., muscle endurance), but also a greater maintenance of high repetition velocities, may be critical for performance.

KEY WORDS. biceps brachii, average repetition velocity, local muscular endurance, short-term resistance training

INTRODUCTION

Resting period between sets and exercises is one of the several variables that can be manipulated when resistance training programs are designed. Classically, the amount of rest between sets can affect the hormonal, metabolic, and the immune responses during strength and power training (7–11). However, only a few longitudinal studies suggest that different resting intervals between sets will significantly affect the gains in maximal strength, muscle power, and local muscular endurance (2, 12, 14). Strength training that consists of moderate-length resting periods (2–3 minutes) between sets has been shown to lead from moderately higher to similar strength and muscle mass gains compared with short resting periods (SR; 30–60 seconds) (2, 12, 14). Thus, the role of the amount of rest between sets to failure to optimize muscle performance remains unclear.

In addition, performance in several sport modalities is not only related to performing a high number of repetitions with a submaximal pretraining load, but also to maintaining a high repetition velocity along a given exercise (4, 5). In this line, the impact of resting period length manipulation after a short-term resistance training (i.e., 5 weeks) on repetition velocity declines during a moderate-intensity bout remains to be elucidated.

In light of these observations, we hypothesized that a training approach with SR periods between sets would result in a higher fatigue state, providing subsequently favorable conditions for improving local muscular endurance and sustained repetition velocity over a set of repetitions to failure. Therefore, the purpose of this study was to examine short-term resistance training effects of resting period length on elbow-flexor number of repetitions and mean velocity over a moderate-intensity set to failure in untrained subjects. A secondary purpose was to examine the underlying neuromuscular adaptations to training by these 2 resting period training protocols.

METHODS

Experimental Approach to the Problem

A longitudinal research design with 2 different resting period lengths was used to sort out differential training adaptations of elbow flexors on maximal isometric strength, maximal number of repetitions, and mean velocity over a set of repetitions to failure with a submaximal load (60% of the pretraining maximum voluntary isometric contraction [MVIC]). Following baseline testing, 21 untrained subjects were randomly divided into 3 experimental groups: SR between sets (1 minute [$n = 7$]), long rest between sets (4 minutes; LR [$n = 7$]), and nontraining control group (CG, $n = 7$). The SR and LR trained in an arm-curl machine 2 days per week for 5 weeks. Prior to data collection, subjects were informed

TABLE 1. Training characteristics and number of repetitions completed during each training session.*

	Week 1		Week 2		Week 3		Week 4		Week 5		
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
Load (%MVIF)	60	60	60	60	65	65	70	70	75	75	
Volume (sets)	3	3	3	3	3	3	3	3	3	3	
Repetitions											Total
SR	32 ± 11	35 ± 13	39 ± 11	38 ± 6	35 ± 9	35 ± 5	33 ± 6	34 ± 6	31 ± 5	31 ± 5	343 ± 72
LR	48 ± 4	50 ± 8	51 ± 7	55 ± 8	48 ± 13	49 ± 13	44 ± 12	44 ± 11	42 ± 10	42 ± 9	448 ± 86†

* Values for number of repetitions completed are mean ± *SD*.
† Significantly different ($p < 0.05$) from the SR.

about the requirements associated with participation in the study, and they provided written informed consent. All procedures were approved by the local Institutional Review Board for the protection of human subjects. Given that metabolic demand and fatigue are important stimuli to improve local muscular endurance, we hypothesized that SR periods between sets would provide more favorable conditions for improving local muscle endurance as well as delay the rate of velocity decrease over a set of repetitions to failure.

Experimental Procedure

Before starting the training program, subjects completed a 2-day experimental protocol on 2 different occasions separated by a minimum of 48 hours. During the first testing session, each subject was tested for MVIC and surface electromyographic activity (sEMG) with the elbow joint angle at 90°. The subject was in a seated position; hence, both the chair and chest pad were adjusted to keep the shoulder joint at 90° in the sagittal plane, while the arm rested on the pad. The lever arm was bind to a firm surface through a steel chain equipped with a load cell (Globus Ergometer, Globus, Codogne, Italy) in such a manner that force was always applied along the cell axis. Following 3 submaximal warm-up trials, subjects performed 2 maximal 5-second isometric bilateral elbow flexions at a 90° joint angle. A 3-minute resting period was allowed between attempts. The highest force output was selected for further analysis. Myoelectric raw signals were detected with a double-differential technique from the biceps brachii of the subject's dominant arm. The surface electrodes (Ag/AgCl, Skintact, Austria) were connected to a 14-bit analog-to-digital converter (ME6000 Biomonitor, Mega Electronics, Kuopio, Finland) by preamplified cables (Mega Electronics). Surface electromyographic activity raw data were averaged by root mean square to obtain the maximal amplitude of the sEMG signal (sEMGmax).

During subsequent test sessions, each subject was tested to perform a maximal repetitive high-power output set until failure with a submaximal load equivalent to 60% of the subject's MVIC, with the same arm-curl machine employed during the first testing session. Failure was defined as the time point when the handgrip ceased to move, if the subject paused more than 1 second after the eccentric or concentric phase or if the subject was unable to reach the 90° of elbow flexion (4). Angular velocity of elbow flexion was measured indirectly through a rotary encoder (Globus Real Power, Globus) linked at the highest load plate. Average angular velocities for each repetition, as well as number of repetitions, were recorded. For comparison purposes, the velocity of each repetition was expressed as a percentage of the average velocity attained during the fastest repetition, and the number of repetitions was expressed as a percentage of the total number of repetitions. The posttraining test was performed with the same absolute load used during the pretraining evaluation. All the subjects were familiar with the testing protocol, as they had been previously tested with the same testing procedures. The test-retest intraclass correlation coefficients for all strength/power and EMG variables were greater than 0.91, and the coefficients of variation ranged from 0.9 to 2.9%.

Once testing sessions were carried out, the SR and LR started moderate-intensity resistance training to failure of about 5 weeks (2 sessions per week). The training was periodized from middle intensity (60% MVIC) to moderate intensity (75% MVIC). Training program characteristics (intensity and volume) are shown in Table 1. Subjects carried out 3 sets per training session. Each set was performed until failure, and subjects were encouraged to flex the elbow as fast as possible during each repetition. Resting periods between sets were 1 and 4 minutes for the SR and LR groups, respectively. The number of repetitions completed by subjects during each training set was recorded. After such a training program, muscle function measurements were repeated in the same order.

Statistical Analyses

Data are expressed as mean and *SD*. Although all the variables measured were normally distributed (Kolmogorov-Smirnov test), nonparametric tests were selected for statistical analyses. Thus, the Kruskal-Wallis H test was used to determine any differences among the 3 groups' initial values. The training-related changes were compared among the different groups by the Mann-Whitney *U*-test. The pattern of velocity decline over the set of repetitions to failure was analyzed through the Friedman test, using the Wilcoxon test to locate selected pairwise differences. A value of $p \leq 0.05$ was used for establishing statistical significance.

RESULTS

Training Volume Completed

The total number of repetitions performed by the LR group during the training program was significantly higher (31.6%; $p < 0.05$) than that performed by the SR group (Table 1). The SR group was not able to maintain the number of repetitions along the 3 training sets, whereas the LR group kept the same number of repetitions during the first 2 sets, although the number of repetitions dropped out during the third one.

Maximum Voluntary Isometric Contraction and Maximal Number of Repetitions to Failure

No significant differences for any variable were observed in the CG during the training period. Although both the

Table 2. Subject physical and performance characteristics.*

	SR ($n = 7$)	LR ($n = 7$)	CG ($n = 7$)
Age (y)	23.2 ± 2.7	25.5 ± 3.5	26.3 ± 3.6
Body mass (kg)	73.2 ± 10.0	83.0 ± 6.0	78.7 ± 10.3
Height (cm)	177 ± 6.2	178.1 ± 3.3	176.4 ± 4.2
MVIC (kg)			
pretraining	48.4 ± 14.6	47.6 ± 16.2	48.23 ± 11.9
posttraining	54.3 ± 13.5	54.9 ± 12.2	48.6 ± 10.9
sEMGmax (μV)			
pretraining	2,785.4 ± 849.6	2,148.6 ± 767.1	2,203.6 ± 548.4
posttraining	3,287.0 ± 1,174.4	2,634.9 ± 697.0	2,109.9 ± 535.1
Number of repetitions			
pretraining	19.1 ± 6.1	23.0 ± 4.0	20.7 ± 4.5
posttraining	33.2 ± 10.3†	34.2 ± 13.4†	21.0 ± 3.7

* Values are mean ± *SD*.
† Significantly different ($p < 0.05$) from pretraining value.

LR and SR showed slight increases in MVIC and sEMGmax, these changes did not reach statistical significance (Table 2).

The number of repetitions performed with 60% of the MVIC increased significantly in both the SR ($p < 0.01$) and LR ($p < 0.01$) groups (Table 2). No significant differences were observed in the magnitude of increase between the SR (69%) and LR (38%) ($p < 0.07$).

As Figure 1 shows, relative average repetition velocity declined significantly ($p < 0.05$) during the set performed with 60% of the MVIC. At pretraining, the repetitions at which significant decreases ($p < 0.05$) in angular velocity occurred corresponded to repetitions 9, 11, and 10 for the SR, LR, and CG, respectively. When expressed as a percentage of the average angular velocity achieved during the fastest repetition, significant declines in average relative velocity were observed over 50% of the maximal number of repetitions achieved by each group. However, during the posttraining, the repetitions at which significant decreases in the relative velocity occurred corresponded to repetitions 28, 21, and 9 for the SR, LR, and CG, respectively (over 90, 70, and 40% of the total number of repetitions achieved by the SR, LR, and CG, respectively). In the SR group, the average velocity achieved at 40, 50, 60, 70, 80, and 90% of the total number of repetitions completed was significantly higher ($p < 0.05$) than the corresponding average velocity value achieved during pretraining. No significant differences were observed in average relative velocity achieved at any percentage of the maximum number of repetitions between pre- and posttraining in either the CG or LR group.

Discussion

The major finding in this study was that 5 weeks of moderate-intensity resistance training to failure, when allowing 1- or 4-minute resting periods between sets, led to similar gains in the maximal number of repetitions achieved during a set to failure with an absolute pretraining load but did not induce any significant change in MVIC or sEMGmax. In addition, a unique finding of this study was that 5 weeks of strength training with short-length resting periods between sets tended to produce larger increases in the average velocity (expressed as a percentage of the initial value) achieved at 40, 50, 60, 70, 80, and 90% of the total number of repetitions (expressed as a percentage of the total number of repetitions performed), with no changes observed in the LR and CG. Thus, the pattern of decline in the relative average velocity during the set of repetitions to failure was improved through the SR training approach, whereas the LR training approach did not induce any change in this sense. These data indicate that training allowing 1-minute resting periods between sets resulted in lower fatigue and higher maintenance of the average repetition velocity achieved during a set of repetitions to failure.

The amount of rest between sets should be dependent on the training goal, the load lifted, and the training status of the individual (3). Research studies have shown that the amount of rest between sets is a critical variable if the goal is to maintain the same number of repetitions or a similar power output pattern during consecutive sets (1, 6, 13, 15). Similar to previous studies (6, 13), our results showed that the total volume of training (i.e., number of repetitions per set) results from the LR when compared with the SR period duration between sets, indicating that the longer the rest between sets to failure, the larger the total volume completed during a training session. Kraemer (6) reported that football players were able to perform 3 sets of 10RM with a 3-minute rest, whereas the number of repetitions achieved with the same absolute intensity dramatically dropped off when resting periods were reduced to 1 minute. Richmond and Godard (13) showed that if recreational resistance-trained men want to replicate the same number of repetitions performed during multiple sets of bench press, a resting time longer than 5 minutes between sets is needed. Both studies suggest that the longer the rest between sets to failure, the larger the total volume completed during a training session. Therefore, it also appears that the amount of rest may be of some importance in the determination of lifting performance, total training volume, or both when multiple sets are prescribed. However, the larger training volume completed by the LR group did not result in a greater MVIC gain. In fact, the training program designed in the present study was not optimum for maximum strength gains; thus, the lack of a significant increase in the MVIC or sEMGmax is not surprising.

In agreement with other studies, our results indicate that the average repetition velocity naturally slows over a set of repetitions to failure (4), so that in bench press performance, significant declines in the average repetition velocity (expressed as a percentage of the average velocity achieved during the initial repetition) occurred when the number of repetitions was more than 34% of the total number of repetitions performed (4). In the present study, the decrease in the average repetition velocity during a moderate-intensity bout to failure of the elbow flexors was significant when the number of repetitions was more than one-half the total number of repetitions performed. Along these same lines, a major finding of this study was that a training program with SR periods between sets (1 minute) significantly reduces the aforementioned velocity decline. According to our results, it appears that training with short intervals of rest between sets is more efficient for improving local upper-body muscular endurance. Therefore, this would enhance long-term ability to maintain a high average repetition velocity achieved during a set of repetitions to failure.

PRACTICAL APPLICATIONS

The present study shows that allowing 1 or 4 minutes of rest between consecutive sets to failure led to similar gains in local muscular endurance after 5 weeks of elbow-flexor resistance training with submaximal loads. However, the SR protocol resulted in lower fatigue and higher maintenance of the average repetition velocity achieved during a set of repetitions to failure. Therefore, during short-term training periods, the length of the rest period between the sets may not be a critical factor in muscle endurance–types of training protocols as long as muscles are overloaded with training stimuli of sufficient intensity and volume during several sets leading to failure. In contrast, the present study suggests that 1-minute resting periods between sets contribute to maintaining a higher repetition velocity as well as delaying the rate of velocity decrease over a set of repetitions to failure.

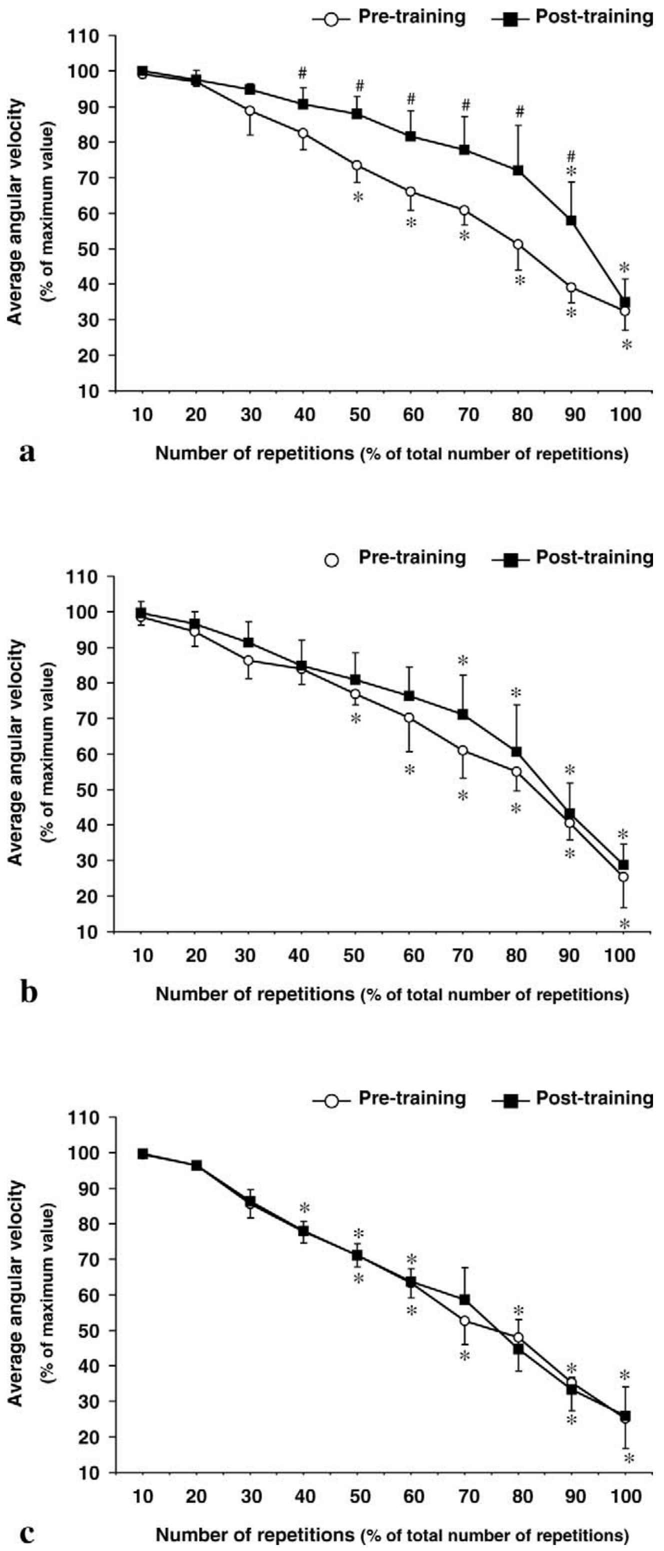

FIGURE 1. Average repetition velocity changes during the maximal number of repetitions to failure test for the short resting periods (a), long rest between sets (b), and nontraining control group (c), both before and after the 5-week training. Average velocity is expressed as a percentage of average velocity achieved during the fastest repetition. Number of repetitions is expressed as a percentage of the total number of repetitions completed. Values are mean ± *SD*. * Significantly different from fastest repetition value ($p < 0.05$). # Significantly different from pretraining value at the same percentage of total repetitions achieved ($p < 0.05$).

REFERENCES

1. ABDESSEMED, D., P. DUCHE, C. HAUTIER, G. POUMARAT, AND M. BEDU. Effect of recovery duration on muscular power and blood lactate during the bench press exercise. *Int. J. Sports Med.* 20:368–373. 1999.
2. AHTIAINEN, J.P., A. PAKARINEN, M. ALEN, W.J. KRAEMER, AND K. HÄKKINEN. Short vs. long rest period between the sets in hypertrophic resistance training: Influence on muscle strength, size, and hormonal adaptations in trained men. *J. Strength Cond. Res.* 19:572–582. 2005.
3. BIRD, S.P., K.M. TARPENNING, AND F.E. MARINO. Designing resistance training programmes to enhance muscular fitness: A review of the acute programme variables. *Sports Med.* 35:841–851. 2005.
4. IZQUIERDO, M., J.J. GONZALEZ-BADILLO, K. HÄKKINEN, J. IBANEZ, W.J. KRAEMER, A. ALTADILL, J. ESLAVA, AND E.M. GOROSTIAGA. Effect of loading on unintentional lifting velocity declines during single sets of repetitions to failure during upper and lower extremity muscle actions. *Int. J. Sports Med.* 27:718–724. 2006.
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. ASLAIN, AND E.M. GOROSTIAGA. Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength and muscle power gains. *J. Appl. Physiol.* 100:1647–1656. 2006.
6. KRAEMER, W.J. A series of studies. The physiological basis for strength training in American football: Fact over philosophy. *J. Strength Cond. Res.* 11:131–142. 1997.
7. KRAEMER, W.J., S.J. FLECK, J.E. DZIADOS, E.A. HARMAN, L.J. MARCHITELLI, S.E. GORDON, R. MELLO, P.N. FRYKMAN, L.P. KOZIRIS, AND N.T. TRIPLETT. Changes in hormonal concentrations after different heavy-resistance exercise protocols in women. *J. Appl. Physiol.* 75:594–604. 1993.
8. KRAEMER, W.J., L. MARCHITELLI, S.E. GORDON, E. HARMAN, J.E. DZIADOS, R. MELLLO, P. FRYKMAN, D. MCCURRY, AND S.J. FLECK. Hormonal and growth factor responses to heavy resistance exercise protocols. *J. Appl. Physiol.* 69:1442–1450. 1990.
9. KRAEMER, W.J., B.J. NOBLE, M.J. CLARK, AND B.W. CULVER. Physiologic responses to heavy-resistance exercise with very short rest periods. *Int. J. Sports Med.* 8:247–252. 1987.
10. KRAEMER, W.J., AND N.A. RATAMESS. Fundamentals of resistance training: Progression and exercise prescription. *Med. Sci. Sports Exerc.* 36: 674–688. 2004.

11. Mayhew, D.L., J.P. Thyfault, and A.J. Koch. 2005. Rest-interval length affects leukocyte levels during heavy resistance exercise. *J. Strength Cond. Res.* 19:16–22. 2005.
12. Pincivero, D.M., S.M. Lephart, and R.G. Karunakara. Effects of rest interval on isokinetic strength and functional performance after short term high intensity training. *Br. J. Sports Med.* 31:229–234. 1997.
13. Richmond, S.R., and M.P. Godard. The effects of varied rest periods between sets to failure using the bench press in recreationally trained men. *J. Strength Cond. Res.* 18:846–849. 2004.
14. Robinson, J.M., M.H. Stone, R.L. Johnson, C.M. Penland, B.J. Warren, and R.D. Lewis. Effects of different weight training exercise/rest intervals on strength, power, and high intensity exercise endurance. *J. Strength Cond. Res.* 9:216–221. 1995.
15. Willardson, J.M., and L.N. Burkett. A comparison of 3 different rest intervals on the exercise volume completed during a workout. *J. Strength Cond. Res.* 19:23–26. 2005.

Address correspondence to Dr. Mikel Izquierdo, mikel.izquierdo@ceimd.org.