The Effect of Aerobic Exercise During the Interset Rest Periods on Kinematics, Kinetics, and Lactate Clearance of Two Resistance Loading Schemes

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Abstract

Mohamad, NI, Cronin, JB, and Nosaka, KK. The effect of aerobic exercise during the interset rest periods on kinematics, kinetics and lactate clearance of two resistance loading schemes. *J Strength Cond Res* 26(1): 73–79, 2012—It may be possible to enhance set and session kinematics and kinetics by engaging in low-intensity aerobic exercise during the interset rest period. The purpose of this study therefore was to quantify the change in session kinematics and kinetics of 35% 1RM and 70% 1RM loading schemes equated by volume, when aerobic exercise or passive rest was undertaken between sets. Twelve male student athletes were recruited for this study. Squat average force, peak force, average power, peak power, total work, and total impulse were quantified using a force plate and linear transducer. Blood lactate samples were taken before set 1, after set 1, after set 2, and after the last set performed. No significant ($p < 0.05$) differences (0.37–9.24%) were found in any of the kinematic and kinetic variables of interset after active or passive interset rest periods. Significant increases (64–76%) in blood lactate occurred from the inception of exercise to completion, for both the heavy and light loading schemes. However, no significant differences in lactate accumulation were noted, whether active or passive recovery was undertaken in the interest rest period. It was concluded that active recovery in the form of low-intensity cycling offered no additional benefits in terms of lactate clearance and enhancement of set and session kinematics and kinetics.

Key Words active recovery, rest interval, force, power, work, impulse, low-intensity aerobic exercise

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Introduction

A great deal of research work has been conducted to investigate the work period during resistance strength training with the intent of maximizing the mechanical stimuli (e.g., force and time under tension) that we present to the muscular system. Improving our mechanical understanding of the training stresses that we impose upon muscle is important because it is thought that strength and power adaptation is mediated by mechanical stimuli and their interaction with hormonal and metabolic factors. In terms of rest however, apart from research that has investigated rest durations between sets (1,11,21,22,29), there has been a paucity of research that has investigated how the rest period may be optimized to enhance session kinematics and kinetics. That is, there may be activities that can be engaged in during the rest period that may enhance the ensuing set and total workout kinematics and kinetics. The net result could be a session with increased mechanical, hormonal, neural, and metabolic outputs and hence the opportunity for improved strength and power adaptation. For this to occur, the interset rest period needs to be viewed, not as a period of passive rest but as a period of recovery, and then use activities that maximize recovery between work bouts for a given purpose.

Of interest to this study is whether active recovery in the form of light aerobic exercise in the interset rest period enhances session kinematics and kinetics. Engaging in active recovery in the interset rest period may enhance transport of glucose, phosphorcreatine regeneration and repletion (36) and positively influence lactate clearance, without adversely affecting session kinematics and kinetics (5,17). Studies have shown that active recovery is an effective means of significantly reducing blood lactate concentration during recovery and increasing performance (5,17) compared with passive recovery. However, we need to be mindful that acute metabolite buildup may increase the secretion of various anabolic hormones or lead to a greater motor unit activation at a given load (14,19,33,34) and in the long term may contribute to some form of strength and power adaptation, for example, hypertrophy (14). Therefore, if metabolite accumulation is an important mediator for hypertrophy by promoting better anabolic hormonal responses, faster lactate clearance may have a negative influence. Conversely, a greater mechanical stimulus (higher forces or greater time under tension) may result from faster lactate clearance and subsequently provide a better strength and power stimulus. Consequently, determining whether light aerobic exercise undertaken in the interset rest period does affect lactate clearance and enhance session kinematics and kinetics should be of interest to the strength and conditioning coach. With this in mind, the purpose of this study is to determine if the lactate clearance and session kinematics and kinetics of 2 loading schemes (35 and 70% 1RM) are affected when short-duration low-intensity aerobic exercise (cycling) is performed during the interset rest periods. The 35 and 70% loads were used as indicative of loading commonly used by practitioners when training power and strength (hypertrophy type loading).

Methods

Experimental Approach to the Problem

In this acute randomized within-subject crossover design, 12 recreationally trained male student athletes were recruited to investigate the effects of load on set and session free weight squat kinematics and kinetics and lactate clearance. Active (indoor cycling) or passive (standing) rest was undertaken during the interset rest periods. Two loading schemes were equated by volume (3 sets of 12 reps at 70% 1RM vs. 6 sets of 12 reps at 35% 1RM) and the dependent variables of interest that were quantified during the eccentric and concentric phases were as follows: average force (AF), peak force (PF), average power (AP), peak power (PP), work (TW), and total impulse (TI). The average repetition value for each set and the total set and session values of each of the variables for both the eccentric and concentric phases were then used for statistical analysis.

Subjects

Twelve recreationally trained male athletes volunteered to participate in this research. Subject mean (±*SD*) age, height, mass, and 1RM squat strength were 26.0 (3.5) years, 173.4 (5.9) cm, 79.3 (10.2) kg, and 119.8 (30.5) kg, respectively. All the subjects recruited were considered injury free as indicated by no lower limb and spine injury record for the past 2 years. The subjects completed an informed consent form before the experiment. Ethics approval from the Human Research Committee of Edith Cowan University was also obtained before commencing the study.

Equipment

The subjects performed the squat on a force plate (400 Series, Fitness Technology, Adelaide, Australia) supported by a Power Cage (FT 700, Fitness Technology). The Olympic bar was interfaced with the Ballistic Measurement System (BMS, Fitness Technology), which consisted of a position transducer (Celesco, PT5A-0150-V62-UP-1K-M6, Chatsworth, CA, USA), computer interface (XPV Interface, Fitness Technology), and the BMS software (BMS, Version 2007.2.3, Innervations, Adelaide, Australia). The sampling frequency of the BMS system was set at 200 Hz. Rest period duration was determined by an electronic stopwatch. Cycling was performed on a cycle ergometer (Repco, Australia) placed next to the power cage where the subjects performed the squat. Cycling exercise heart rate was monitored using a Polar heart rate monitor (Polar S810, Pursuit Performance Pty Ltd, Adelaide, Australia).

Finger prick blood lactate samples were collected and analyzed using spring loaded lancets, test strips, and a lactate analyzer (Lactate Pro™ LT 1710, Arkray Factory, Inc., Kyoto, Japan).

Procedures

The procedures involved one familiarization and 4 testing sessions. The testing sessions were randomized to eliminate any learning, order, or fatigue effects that could confound the statistical analysis. A minimum of 72 hours' rest was given between all sessions to ensure full recovery. The participants were asked to replicate exercise and dietary intake 24 hours before each testing occasion.

Preliminary Assessments and Familiarization. During the first session, technique and maximum squat strength (1RM) were assessed and anthropometric measurements taken. The anthropometric variables of interest included standing height (centimeters) and body mass (kilograms). Movement for the half-squat was analyzed, and corrections to technique were made as necessary. Half-squat 1RM was determined according to standardized procedures. The participants were asked to provide their estimated half-squat 1RM based on their past performance. A 5-minute general warm-up was undertaken. Each participant was then required to perform 2 warm-up sets of 8 reps at 50% of estimated 1RM and 3 reps at 70% of estimated 1RM, respectively. After a 5-minute rest, each subject's 1RM was determined (4- to 5-minute rest in between 1RM lifts).

Squat Technique. The squat movement began from a standing position with the feet approximately shoulder width apart. The squat was initiated by a controlled downward eccentric knee bend until the top of the thighs became parallel to the floor, which was followed by a concentric phase.

Cycling Exercise. Cycling exercise was undertaken during the 90-second interset rest period at a self-selected resistance with velocity between 50 and 70 rpm and heart rate response of 50–60% of the maximum heart rate (MHR), this intensity having been reported as a suitable warm-up intensity (12,13). The MHR was calculated using the following equation: $\text{MHR} = 205.8 - (0.685 \times \text{age})$ (30).

Intervention. The subjects were randomly allocated to 1 of 4 interventions (35% of 1RM [active and passive recovery] and 70% of 1RM [active and passive recovery]). The participants warmed up as described previously before each testing session, for example, jogging and warm-up sets. The subjects then performed either 6 sets of 12 reps at 35% of 1RM or 3 sets

TABLE 1. Average total eccentric values (mean ± *SD*) for the 35% 1RM schemes with active and passive recovery intervention in between sets.*

Variable	35% 1RM (passive)	35% 1RM (active)	% Difference	Significance
Average force (N)	4,729 ± 2,371	4,996 ± 2,056	5.34	0.495
Peak force (N)	14,623 ± 2,037	14,248 ± 2,374	2.56	0.214
Average power (W)	10,907 ± 2,628	10,319 ± 2,202	5.39	0.165
Peak power (W)	21,313 ± 6,134	19,980 ± 4,850	6.25	0.211
Total work (J)	5,483 ± 845	5,342 ± 890	2.57	0.477
Total impulse	7,794 ± 1,295	7,605 ± 1,580	2.42	0.437

*1RM = 1 repetition maximum.

of 12 reps at 70% of 1RM loading. A 90-second interset rest period was used for all conditions. For the active recovery intervention sessions, the subjects used the 90 seconds of the rest period to cycle on the cycle ergometer as described previously, before continuing the next squat set.

Statistical Analyses

The force plate was synchronized with a linear position transducer attached to the bar to measure the various dependent variables of interest. Data were collected with an analog-to-digital conversion rate of 200 Hz. Displacement data from the linear position transducers were smoothed with a cut-off frequency of 10 Hz using low-pass fourth order Butterworth filter. The eccentric (maximum to minimum vertical displacement) and concentric (minimum to maximum vertical displacement) phases were determined from the linear position transducer. All variables of interest (AF, PF, AP, PP, TW, and TI) were calculated for each eccentric and concentric contractions for each repetition, and for each set and session involved, via the BMS software data analysis program. System mass was used (sum of external load and body mass) in the force calculation of the BMS. The reliability and validity of the force plate and position transducers used in this study have been widely established via many similar previous studies (6,8,9,31), with reliability and validity report of the BMS measurement being also available within the manufacturer's website at http://www.innervations.com/ballistic/validationofsystem.htm.

The average repetition value for each set was calculated and used for the repetition analysis (Tables 1 and 2). The summed repetition and set values for each session were used as the total session kinematics and kinetics and compared between loading schemes (Tables 3 and 4).

Finger prick blood samples (5 μL) for lactate concentration were collected before set 1, after set 1, after set 2, and after the last set performed using the method as described by Corder et al. (5). Collected finger prick blood samples were immediately placed on test strips and analyzed using the lactate analyzer for lactate concentration. After completing the exercise sets, the subjects waited passively in the laboratory until all data were collected.

Means and *SD*s were used to represent centrality and spread of data. The analysis of interest was whether the aerobic intervention affected the session kinematics and

TABLE 2. Average total concentric values (mean ± *SD*) for the 35% 1RM schemes with active and passive recovery intervention in between sets.*

Variable	35% 1RM (passive)	35% 1RM (active)	% Difference	Significance
Average force (N)	13,965 ± 1,837	14,017 ± 2,213	0.37	0.861
Peak force (N)	22,318 ± 3,329	21,413 ± 2,983	4.06	0.100
Average power (W)	10,753 ± 2,015	10,166 ± 2,002	5.92	0.104
Peak power (W)	22,178 ± 6,220	20,665 ± 5,916	6.82	0.138
Total work (J)	103,169 ± 20,676	97,644 ± 21,516	5.36	0.212
Total impulse	7,064 ± 1,326	6,860 ± 1,545	2.89	0.439

*1RM = 1 repetition maximum.

TABLE 3. Average total eccentric values (mean ± *SD*) for the 70% 1RM schemes with active and passive recovery intervention in between sets.*

Variable	70% 1RM (passive)	70% 1RM (active)	% Difference	Significance
Average force (N)	12,654 ± 3,506	13,440 ± 5,894	5.85	0.641
Peak force (N)	19,126 ± 3,136	19,816 ± 5,990	3.48	0.637
Average power (W)	7,521 ± 1,535	7,805 ± 3,213	3.64	0.732
Peak power (W)	14,395 ± 2,921	14,966 ± 5,508	3.82	0.664
Total work (J)	6,948 ± 2,119	7,179 ± 3,220	3.22	0.761
Total impulse	17,455 ± 5,659	19,232 ± 8,248	9.24	0.296

*1RM = 1 repetition maximum.

kinetics of each loading scheme (i.e., 35% 1RM with and without cycling and 70% 1RM with and without cycling). With this in mind, Paired sample *t*-test comparisons were used to determine if significant differences existed between the dependent variables (eccentric and concentric AF, PF, AP, PP, TW, and TI) across the 2 loading schemes. The percent difference between loading schemes were calculated (% Difference = (1 − Lowest Variable/Highest Variable) × 100. Repeated measures analyses of variance with post hoc contrasts were used to determine if significant differences existed across time points for the lactate measurements. An alpha level of 0.05 was set to assess the statistical significance for all tests.

RESULTS

As can be observed from Table 1 (eccentric contraction) and Table 2 (concentric contraction), the percent differences between variables for the 35% 1RM condition ranged from 0.37 to 6.82%, and most of the variables apart from AF (5.34%) were less after the active recovery intervention. However, none of these differences were statistically significant.

With regards to the 70% 1RM condition, it can be observed from Table 3 (eccentric contraction) and Table 4 (concentric contraction) that the differences between variables for the 70% 1RM condition ranged from 1.68 to 13.9%. Except for TW, all other variables in both the eccentric and concentric phases were greater after the cycling intervention. Once more, none of these differences were statistically significant.

In terms of blood lactate accumulation and clearance, nonsignificant differences in lactate levels for both the 35 and 70% 1RM loading were found when both active and passive recovery methods were used. These nonsignificant differences were found between all time points (i.e., before and post each set) and ranged from 0.15 to 27% (Tables 5 and 6). However, blood lactate levels were found to significantly increase (~65–77%) from the inception of exercise across the time points for both loadings either with or without active recovery. Interestingly, lower levels of lactate accumulation (~65–68%) were associated with the lighter loading scheme even though both loading schemes were equated by volume ($p < 0.05$).

TABLE 4. Average total concentric values (mean ± *SD*) for the 70% 1RM schemes with active and passive recovery intervention in between sets.

Variable	70% 1RM (passive)	70% 1RM (active)	% Difference	Significance
Average force (N)	18,831 ± 3,151	19,152 ± 6,391	1.68	0.835
Peak force (N)	23,384 ± 2,956	23,835 ± 6,177	1.89	0.781
Average power (W)	8,789 ± 1,320	9,441 ± 3,336	6.91	0.472
Peak power (W)	16,507 ± 3,545	18,066 ± 6,464	8.63	0.328
Total work (J)	96,523 ± 19,704	83,097 ± 42,260	13.9	0.577
Total impulse	14,321 ± 4,402	15,230 ± 6,671	5.97	0.502

*1RM = 1 repetition maximum.

TABLE 5. Average blood lactate accumulation values (mean ± *SD*) for the 70% 1RM loading scheme before and after active and passive recoveries.*

Set	70% 1RM (passive)	70% 1RM (active)	% Difference	Significance (*t*-test)
Before set 1	1.75 ± 0.56	1.55 ± 0.56	11.0	0.420
Post set 1	4.38 ± 1.16	5.37 ± 2.79	18.0	0.179
Post set 2	5.64 ± 1.21	5.84 ± 1.69	3.00	0.693
Post final set	6.67 ± 1.67	6.66 ± 1.93	0.15	0.984
% Difference	73.8	76.7		

*1RM = 1 repetition maximum.

TABLE 6. Average blood lactate accumulation values (mean ± *SD*) for the 35% 1RM loading scheme before and after active and passive recoveries.*

Set	35% 1RM (passive)	35% 1RM (active)	% Difference	Significance (*t*-test)
Before set 1	1.58 ± 0.63	1.58 ± 0.40	0	0.967
Post set 1	3.59 ± 1.60	2.62 ± 0.36	27.0	0.084
Post set 2	4.13 ± 1.15	3.56 ± 0.63	14	0.244
Post final set	4.93 ± 1.80	4.47 ± 0.68	9.00	0.378
% Difference	68.0	64.7		

*1RM = 1 repetition maximum.

DISCUSSION

Although the effectiveness of active recovery after moderate-duration exercise is well documented (2,10,20,25), few investigations (4,32,37) have determined the impact of short-duration active recovery (<10 minutes) on high-intensity exercise, and most of these studies are not specific to resistance strength training nor have they investigated active recovery specific to the 60- to 90-second interset rest periods used in this study. This study found that low-intensity aerobic exercise performed during the interset rest period did not have a statistically significant influence on the kinematics and kinetics of the ensuing sets. Our results also indicated that blood lactate accumulation and clearance remained relatively similar irrespective of the type of recovery (active vs. passive) and training load (35 vs. 70% 1RM). An elevation in lactate levels was observed in both loading schemes; however, the magnitude of this increase was less in the light load scheme.

Previous studies have found that active recovery increased blood flow to the previously exercised muscle and was more effective compared with short-term body massage and passive rest in improving lactate removal (4,16). Hannie et al. (17) found that active recovery was more effective in clearing lactate and producing greater isometric force as compared with passive rest. However, the effect of active recovery on session kinematics and kinetics and lactate clearance was not statistically different ($p > 0.05$) to passive rest in this study. The differences between the findings of this study and those of other studies may be explained by the methodological design differences. For example, Hannie et al. (17) did not equate workload, because the maximum number of exercise repetitions performed was of primary importance in their study. Furthermore, the differences in work:rest ratios make comparisons between studies difficult.

Even though no significant differences were found in session kinematics and kinetics when active recovery was used in the interset rest period, this does not preclude the contention that other benefits may be afforded by performing light aerobic exercise between sets. For example, aerobic exercise that has increased and maintained muscle temperature has been shown to enhance neural transmission (15,24), increase muscle compliance (23), and improve mechanical efficiency (3).

It should be realized that the methodology used in this study is only a snapshot of what typically occurs in a resisted strength training session. For example, a typical hypertrophy loading scheme would be characterized by a greater volume and can include at least 6–8 exercises per session, the total sets per session could be between 24 and 32 sets per session (7,8,18,26–28). This combined with interset rest periods of approximately 60–90 seconds results in total session durations of at least 60 minutes and total session recovery of approximately 24–40 minutes. Implicitly in this is that a great deal of more work is performed in a typical training session, and with the possibility of 30–40 minutes of aerobic exercise, the results of this study then, will not be able to be generalized into a typical training session as the acute adaptations may differ markedly.

Another limitation of this study revolves around determining the individual appropriate aerobic threshold that might stimulate the sought-after adaptations. That is, subjects' exercise intensity was self-selected and therefore might not have been appropriate to stimulate the required adaptation, that is, better kinematics and kinetics and lactate clearance. Furthermore, finding appropriate aerobic thresholds that positively influence hormonal, metabolic, neural, and mechanical responses certainly needs investigation.

Even though both the loading schemes were equated by volume, significantly lower lactate levels were associated with the lighter load intervention. Heavier loading has long been found to elicit greater metabolic stress (35) and trigger higher rate of anabolic hormones secretion (14,19,33,34). Therefore, if metabolite accumulation is an important mediator for adaptation such as hypertrophy by promoting better anabolic hormonal responses, the heavier loading scheme would seemingly optimize this response, because faster lactate clearance may have a negative influence. Conversely, a greater mechanical stimulus (higher forces or greater time under tension) may result from faster lactate clearance and provide a better strength stimulus. However, longitudinal studies need to be conducted before this contention can be ascertained.

Practical Applications

Currently, most typical resistance loading schemes use passive recovery in between sets. It was thought that active recovery using low-intensity aerobic exercise may have beneficial effects for a training session in terms of better lactate clearance and enhanced session kinematics and kinetics. Even though this was not found to be the case in this study, the strength and conditioning coach should not dispel the utility of such a practice, given the limitations of this study. Some of the benefits of including light aerobic activity in the interset rest period that were not measured include improved substrate repletion; increased anabolic hormonal responses; improved neural transmission; increased muscle compliance; and, improved mechanical efficiency. However, whether such adaptations occur is no doubt dependent on the intensity and the duration of the aerobic activity used in the interset rest period. Finding individualized aerobic thresholds that positively influence hormonal, metabolic, neural, and mechanical responses certainly needs a great deal more research. In the first instance, it needs to be determined whether such interset aerobic activity (individualized thresholds) negatively influences total session kinematics and kinetics. If there is no significant decrease in session kinematics and kinetics, then the acute effects of interset aerobic activity on the variables of interest need investigation. Finally, longitudinal studies are needed to quantify the change in the variables of interest using such recovery periods.

References

1. Ahtiainen, JP, Pakarinen, A, Alen, M, Kraemer, WJ, and Hakkinen, K. 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.
2. Belcastro, AN and Bonen, A. Lactic acid removal rates during controlled and uncontrolled recovery exercise. *J Appl Physiol* 39: 932–936, 1975.
3. Bell, MP and Ferguson, RA. Interaction between muscle temperature and contraction velocity affects mechanical efficiency during moderate-intensity cycling exercise in young and older women. *J Appl Physiol* 107: 763–769, 2009.
4. Bogdanis, GC, Nevill, ME, Lakomy, HKA, Graham, CM, and Louis, G. Effects of active recovery on power output during repeated maximal sprint cycling. *Eur J Appl Physiol* 74: 461–469, 1996.
5. Corder, KP, Potteiger, JA, Nau, KL, Figoni, SF, and Hershberger, SL. Effects of active and passive recovery conditions on blood lactate, rating of perceived exertion, and performance during resistance exercise. *J Strength Cond Res* 14: 151–156, 2000.
6. Cormie, P, McBride, JM, and McCaulley, GO. Power-time, force-time, and velocity-time curve analysis during the jump squat: Impact of load. *J Appl Biomech* 24: 112–120, 2008.
7. Crewther, B, Cronin, JB, Keogh, J, and Cook, C. The salivary testosterone and cortisol response to three loading schemes. *J Strength Cond Res* 22: 250–255, 2008.
8. Crewther, BT, Cronin, J, and Keogh, JWL. The contribution of volume, technique, and load to single-repetition and total-repetition kinematics and kinetics in response to three loading schemes. *J Strength Cond Res* 22: 1908–1915, 2008.
9. Cronin, JB and Crewther, B. Training volume and strength and power development. *J Sci Med Sport* 7: 144–155, 2004.
10. Davies, C, Knibbs, A, and Musgrove, J. The rate of lactic acid removal in relation to different baselines of recovery exercise. *Eur J Appl Physiol Occup Phys* 28: 155–161, 1970.
11. Denton, J and Cronin, JB. Kinematic, kinetic and blood lactate profiles of continuous and intraset rest loading schemes. *J Strength Cond Res* 20: 528–534, 2006.
12. Fox, SM and Haskell, WL, ed. The exercise stress test: Needs for standardization In: *Cardiology Current Topics and Progress*. New York, NY: Academic, 1970. pp. 149.
13. Fox, SM, Naughton, JP, and Haskell, WL. Physical activity and the prevention of coronary heart disease. *Ann Clin Res* 3: 404–432, 1971.
14. Goto, K, Ishii, N, Kizuka, T, and Takamatsu, K. The impact of metabolic stress on hormonal responses and muscular adaptations. *Med Sci Sports Exerc* 37: 955–963, 2005.
15. Gray, SR, De Vito, G, Nimmo, MA, Farina, D, and Ferguson, RA. Skeletal muscle ATP turnover and muscle fiber conduction velocity are elevated at higher muscle temperatures during maximal power output development in humans. *Am J Physiol Regul Integr Comp Physiol* 290: R376–R382, 2006.
16. Gupta, S, Goswami, A, Sadhukan, AK, and Mathur, DN. Comparative study of lactate removal in short term massage of extremities, active recovery and a passive recovery period after supramaximal exercise sessions. *Int J Sports Med* 17: 106–110, 1996.

17. Hannie, PQ, Hunter, GR, Kekes-Szabo, T, Nicholson, C, and Harrison, PC. The effects of recovery on force production, blood lactate, and work performed during bench press exercise. *J Strength Cond Res* 9: 8–12, 1995.

18. Kraemer, WJ and Ratames, NA. Fundamentals of resistance training: Progression and exercise prescription. *Med Sci Sports Exerc* 36: 674–688, 2004.

19. Kraemer, WJ, Staron, RS, Hagerman, FC, Hikida, RS, Fry, AC, Gordon, SE, Nindl, BC, Gothshalk, LA, Volek, JS, Marx, JO, Newton, RU, and Häkkinen, K. The effects of short-term resistance training on endocrine function in men and women. *Eur J Appl Physiol.* 78: 69–76, 1998.

20. Lars, H and Inger, S. Production and removal of lactate during exercise in man. *Acta Physiol Scand* 86: 191–201, 1972.

21. Lawton, TW, Cronin, JB, Drinkwater, E, Lindsell, R, and Pyne, D. The effect of continuous repetition training and intra-set rest training on bench press strength and power. *J Sports Med Phys Fitness* 44: 361–367, 2004.

22. Lawton, TW, Cronin, JB, and Lindsell, RP. Effect of interrepetition rest intervals on weight training repetition power output. *J Strength Cond Res* 20: 172–176, 2006.

23. McNair, PJ and Stanley, SN. Effect of passive stretching and jogging on the series elastic muscle stiffness and range of motion of the ankle joint. *Br J Sports Med* 30: 313–317, 1996.

24. Mika, A, Mika, P, Fernhall, B, and Unnithan, VB. Comparison of recovery strategies on muscle performance after fatiguing exercise. *Am J Phys Med Rehabil* 86: 474–481, 2007.

25. Monedero, J and Donne, B. Effect of recovery interventions on lactate removal and subsequent performance. *Int J Sports Med* 21: 593–597, 2000.

26. Mulligan, SE, Fleck, SJ, Gordon, SE, Koziris, LP, Triplett-McBride, NT, and Kraemer, WJ. Influence of resistance exercise volume on serum growth hormone and cortisol concentrations in women. *J Strength Cond Res* 10: 256–262, 1996.

27. Peterson, MD, Kampert, M, Haff, GG, and Gordon, PM. The contribution of volume load variation on strength and hypertrophy during unilateral resistance training in the elbow flexors. *J Strength Cond Res* 24:1-10, 2010.

28. Ratamess, NA, Alvar, BA, Evetovich, TK, Housh, TJ, Kibler, WB, Kraemer, WJ, and Triplett, NT. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.

29. Ratamess, NA, Falvo, MJ, Mangine, GT, Hoffman, JR, Faigenbaum, AD, and Jie, K. The effect of rest interval length on metabolic responses to the bench press exercise. *Eur J Appl Physiol* 100: 1–17, 2007.

30. Robergs, RA and Landwehr, R. The surprising history of the "HRmax = 220 − age" equation. *J Exerc Physiol Online* 5: 1–10, 2002.

31. Sheppard, JM, Doyle, TLA, and Taylor, DC. A methodological and performance comparison of free weight and smith-machine jump squats. *J Aust Strength Cond* 16: 5–9, 2008.

32. Signorile, JF, Ingalls, C, and Tremblay, LM. The effects of active and passive recovery on short-term, high intensity power output. *Can J Appl Physiol* 18: 31–42, 1993.

33. Takarada, Y, Nakamura, Y, Aruga, S, Onda, T, Miyazaki, S, and Ishii, N. Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. *J Appl Physiol* 88: 61–65, 2000.

34. Taylor, JM, Thompson, HS, Clarkson, PM, Miles, MP, De Souza, MJ, and Taylor, JM. Growth hormone response to an acute bout of resistance exercise in weight-trained and non-weight-trained women. *J Strength Cond Res* 14: 220–227, 2000.

35. Tesch, P, Colliander, E, and Kaiser, P. Muscle metabolism during intense, heavy-resistance exercise. *Eur J Appl Physiol Occup Phys* 55: 362–366, 1986.

36. Tomlin, DL and Wenger, HA. The relationship between aerobic fitness and recovery from high intensity intermittent exercise. *Sports Med* 31: 1–11, 2001.

37. Weltman, A, Stamford, B, Moffat, RJ, and Katch, VL. Exercise recovery, lactate removal, and subsequent high intensity exercise performance. *Res Q* 48: 786–796, 1977.