

Effects of Active and Passive Recovery Conditions on Blood Lactate, Rating of Perceived Exertion, and Performance During Resistance Exercise

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ABSTRACT

Active recovery has proven an effective means in reducing blood lactate concentration ($[La^-]$) after various activities, yet its effects on performance are less clear. We investigated the effects of passive and active recovery on blood $[La^-]$, rating of perceived exertion (RPE), and performance during a resistance training workout. Fifteen resistance-trained males completed 3 workouts, each consisting of 6 sets of parallel squat exercise performed at 85% of 10 repetition maximum (10RM). Each set was separated by a 4-minute recovery period. Recovery was randomly assigned from the following: passive sitting; pedaling at 25% of onset of blood lactate accumulation (OBLA) exercise intensity (25%-OBLA); and pedaling at 50% of OBLA exercise intensity (50%-OBLA). Active recovery was performed on a bicycle ergometer at 70 $rev \cdot min^{-1}$. Performance was determined postworkout by a maximal repetition performance (MRP) squat test using 65% of 10RM. Blood samples were collected: prewarm-up; post-second, postfourth, postsixth, and MRP sets; and postsecond, postfourth, and postsixth recovery periods. Significant differences ($p \leq 0.05$) were observed in $[La^-]$, and RPE among the 3 recoveries, with 25%-OBLA lower than passive and 50%-OBLA. Total repetitions to exhaustion for the MRP were: passive (24.1 ± 1.8); 25%-OBLA (29.3 ± 1.8); and 50%-OBLA (23.1 ± 1.7), with 25%-OBLA being significantly greater than passive and 50%-OBLA. In this investigation, active recovery at 25%-OBLA proved to be the most effective means of reducing $[La^-]$ during recovery and increasing performance following a parallel squat workout.

Key Words: onset of blood lactate accumulation, exercise, training

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Introduction

Results obtained from past investigations indicate that performance may be adversely affected by elevated blood lactate concentration ($[La^-]$) (17, 25, 27). High-intensity muscular contractions add to both intramuscular and circulating levels of La^- and hydrogen ions (H^+) (11, 15) that will retard the rate of glycolysis by inhibiting the activity of glycolytic enzymes (7) or interfere with the muscle contraction process (12, 20). The removal of La^- and H^+ from the active muscle and blood after high-intensity exercise is thought to be critical to subsequent peak performance (19).

There is a significant amount of literature identifying the positive aspects of an active recovery on La^- removal during subsequent bouts of exercise lasting 15–30 minutes. Previous investigations (2, 8, 9, 11, 21) have shown that La^- removal occurs more rapidly during continuous aerobic recovery. Specifically, Hermansen and Stensvold (11) found that the greatest reductions in blood $[La^-]$ occurred at an average of 63% of maximal aerobic power ($\dot{V}O_{2max}$). Additional investigations have found that the rate of blood La^- disappearance is related to the intensity of the recovery exercise with optimal removal occurring between 25% and 63% of $\dot{V}O_{2max}$ (2, 8, 11).

Although the effectiveness of active recovery following moderate-duration exercise is well documented (2, 8, 11, 24, 29), few investigations (3, 23, 30) have determined the impact of short duration active recovery (<10 minutes) on high-intensity exercise. Stamford et al. (24) and Weltman et al. (29) found an increase in lactate clearance when using an active recovery following supramaximal and maximal exercise, respectively. Recently, Signorile et al. (23) examined performance during a series of 8 6-second supramaximal rides on a modified cycle ergometer separated by 30-second active or passive recovery periods. Their results indicated that active recovery provides superior performance over passive rest in repeated short-term, high-intensity

power activities. Weltman et al. (30) reported that when a 1-minute cycle ergometer ride was followed by either passive or active recovery, the active recovery produced significantly higher power output in a subsequent effort. This improved performance was attributed to increased rates of La^- clearance. Bogdanis et al. (3) had subjects perform 2 maximal effort 30-second cycle ergometer sprints, separated by 4 minutes of either active or passive recovery. Active recovery resulted in a significantly higher mean power output during sprint 2 compared to passive recovery.

To our knowledge, the impact of active versus passive recovery on La^- metabolism and performance during resistance training exercise has not been reported. Resistance-trained athletes, such as bodybuilders or power-lifters, must perform exercises at maximal or near maximal intensities with repeated efforts in order to enhance muscular hypertrophy and/or strength. Recovery between efforts for these athletes may be a critical issue for maximizing performance; however, to our knowledge no investigations have examined this issue. Therefore, the purpose of this study was to determine the effects of active and passive recovery on blood $[\text{La}^-]$, rating of perceived exertion (RPE), and performance on a maximal test of parallel squats.

Methods

Subjects

Fifteen resistance-trained males volunteered to participate in the study. The physical characteristics (mean \pm *SD*) of the subjects were as follows: age (23.5 ± 1.3 years); height (177.5 ± 1.4 cm); body mass (88.3 ± 2.9 kg); and 10 repetition maximum in the parallel squat (150.7 ± 4.8 kg). Prior to participation in the study, each subject received an explanation of the procedures and provided written informed consent in accordance with university guidelines for human experimentation. The criteria for acceptance as a subject included participation in a current resistance-training program at least 3 d·wk⁻¹ for a minimum of 6 months prior to starting the investigation and no medical contraindications. During the study the subjects refrained from consuming any food or beverage for at least 3 hours before each testing session, participating in any type of exercise for at least 24 hours prior to each exercise test, and participating in any type of lower extremity exercise for a minimum of 3 days prior to each exercise test. For the duration of the study subjects were instructed to maintain normal dietary patterns and refrain from using any ergogenic aids.

Study Design

There were 5 testing sessions, with each session performed at the same time of day for a given subject. The first session involved the collection of physical data and performance of a graded exercise test (GXT).

The second session was used for determination of the subject's 10 repetition maximum (10RM). Sessions 3–5 were used for examining the influence of active and passive recovery on blood $[\text{La}^-]$, RPE, and performance during a parallel squat workout.

GXT and Strength Testing

During the first session, subjects performed a GXT to determine the onset of blood lactate accumulation (OBLA) and peak oxygen consumption ($\dot{V}\text{O}_{2\text{peak}}$) on a Monark 818E cycle ergometer. The test began at a power output of 40 W and was increased by 40 W every 3 minutes until subjects were unable to maintain a pedaling cadence of 70 rev·min⁻¹. Expired gases were collected from the subjects using a 1-way valve and analyzed for oxygen and carbon dioxide concentrations using a Sensormedics 2900 Metabolic Measurement Cart (Yorba Linda, CA). The flow meter and gas analyzers were calibrated prior to each test using a 3-L gas syringe and gases of known concentrations, respectively. Heart rate and RPE were recorded at 30 seconds prior to the end of each exercise stage during the test with the use of a Polar heart rate telemetry unit (Polar Electro Inc., Port Washington, NY) and the 10-point Borg category-ratio scale, respectively (5). Achieving any 2 of the 3 following criteria constituted attainment of $\dot{V}\text{O}_{2\text{peak}}$: a plateau of the oxygen uptake with an increase in power output; a respiratory exchange ratio >1.10 ; and heart rate within ± 10 beats·min⁻¹ of age-predicted maximum (22).

Fingerstick samples of blood were collected at rest and during the last 30 seconds of each exercise stage. Samples were immediately analyzed for blood $[\text{La}^-]$ using a calibrated YSI 1500 Sport L-lactate analyzer (Yellow Springs, OH). For this study the OBLA was operationally defined as the power output corresponding to the 4.0 mmol·L⁻¹ blood $[\text{La}^-]$ (10). The exercise intensity equivalent to 25% and 50% of the OBLA (25%-OBLA and 50%-OBLA) was calculated and used during the active recovery periods of the resistance training workout.

At least 48 hours after completion of the GXT, each subject performed a strength test to determine his 10RM for the parallel squat exercise. The squat exercise was performed using a standard Olympic barbell in a safety rack with each subject wearing a weight belt for low back support. Proper range of motion was signaled to the subject when a parallel position of the femur (midthigh) to the floor was attained. The 10RM dynamic strength test procedure was performed according to a previously described protocol (26). Verbal encouragement was provided to elicit a maximal effort from each subject. The heaviest mass a subject could lift 10 times, determined to the nearest 0.5 kg, provided a measure of that subject's 10RM. From the 10RM observed during the dynamic strength test, the resistance equivalent to 85% of 10RM (mean \pm *SD*, 128.1

Table 1. Blood $[La^-]$ prior to and following a resistance training workout employing different recovery conditions ($N = 15$) (mean \pm SE).*

Condition	Prewarmup	Postset 2	Postrec 2 ^{ac}	Postset 4 ^{ac}	Postrec 4 ^{ac}	Postset 6 ^{abc}	Postrec 6 ^{abc}	Post-MRP set ^{abc}
Passive	1.3 \pm 0.1	4.9 \pm 0.4	5.4 \pm 0.4	6.7 \pm 0.5	6.7 \pm 0.6	7.6 \pm 0.6	7.7 \pm 0.7	9.0 \pm 0.5
25%-OBLa†	1.4 \pm 0.1	4.6 \pm 0.3	4.5 \pm 0.4	5.7 \pm 0.4	5.6 \pm 0.5	6.5 \pm 0.5	6.2 \pm 0.5	8.1 \pm 0.4
50%-OBLa	1.2 \pm 0.1	4.7 \pm 0.3	5.1 \pm 0.4	6.2 \pm 0.5	6.2 \pm 0.5	6.9 \pm 0.5	7.1 \pm 0.6	8.4 \pm 0.4

* Within a measurement, superscript a refers to a significant difference between the passive and 25%-OBLa conditions; superscript b refers to a significant difference between the passive and 50%-OBLa conditions; and superscript c refers to a significant difference between the 25%-OBLa and 50%-OBLa conditions ($p \leq 0.05$).

† OBLa = onset of blood lactate accumulation.

± 4.1 kg) was calculated and used during the parallel squat workout.

Resistance Training Workouts

Each subject returned to the laboratory to perform each of 3 recovery conditions during a parallel squat workout. Each subject started the test session by resting supine for a period of 10 minutes prior to the first blood collection. After resting $[La^-]$ was determined, each subject performed 2 warm-up sets of 10 repetitions at 50% of 10RM. Each set was separated by 4 minutes of passive recovery. After the warm up, all subjects performed 6 sets of 10 repetitions at 85% of 10RM. The 3 recovery conditions were randomly assigned and involved the following: (a) passive recovery, (b) active recovery at 25%-OBLa, and (c) active recovery at 50%-OBLa. Passive recovery (quietly sitting) and active recovery were performed on a Monark 818E cycle ergometer. Following the last recovery period of each parallel squat workout, a maximal repetition performance (MRP) measure was determined by having the subject perform as many repetitions as possible on the parallel squat exercise using 65% of his 10RM (mean \pm SD, 98.0 \pm 3.1 kg). This test has been used previously as a measure of resistance training performance (28). The subjects were instructed to maintain a constant up-down, no-rest cadence until they could no longer successfully complete a repetition.

Blood $[La^-]$ was determined from fingerstick blood samples collected: prewarm-up; postsecond, post-fourth, postsixth, and MRP sets; and postsecond, post-fourth, and postsixth recovery periods. All blood was analyzed using a calibrated YSI 1500 Sport L-lactate analyzer. Within the 4-minute recovery period, blood samples were collected via fingerstick within 30 seconds after completion of each set and within 30 seconds prior to the end of each rest period. Blood samples during active recovery sessions were collected while the subjects were pedaling. An RPE using the 10-point Borg ratio scale (5) was determined at each blood collection point. Each subject then returned within 4–7 days to complete the next testing session.

All 3 testing sessions were completed within a 2-week period.

Data Analysis

In order to determine the appropriate number of subjects to include in this study, a priori power analysis was conducted. Assuming a 2-tailed α of 0.05, a desired level of power of at least 0.80, and an effect size of 0.92, the required sample was approximately 15 subjects (6). Prior to performing the statistical analyses, the assumption of sphericity under repeated-measures analysis of variance (ANOVA) was tested. Huynh-Feldt ϵ values ranged from 0.74 to 1.09 for the ANOVAs, indicating that all assumptions necessary for the use of repeated-measures ANOVA were met (13). Repeated-measures 2-way ANOVA, with $[La^-]$ and RPE as the within-subjects factors and type of recovery as the between-subjects factor, were conducted. Paired t -tests were used to identify mean differences. No correction for multiple hypothesis testing was required because in the specific case when the number of conditions equals 3, a significant omnibus F -ratio itself provides a strong control for the experimentwise error rate (18). Pearson correlation coefficients were used to establish the relationship between $[La^-]$ and RPE versus the number of repetitions performed during the MRP. An α level of 0.05 was set for all statistical testing. All results are reported as mean \pm SEM.

Results

The subjects in this investigation had a $\dot{V}O_{2peak}$ on the cycle ergometer of 41.9 \pm 6.2 ml·kg⁻¹·min⁻¹. The power output at 25%-OBLa was 45.9 \pm 9.1 W and at 50%-OBLa was 73.4 \pm 14.6 W. The oxygen uptake values for the subjects were 6.9 \pm 1.3 ml·kg⁻¹·min⁻¹ and 13.8 \pm 2.5 ml·kg⁻¹·min⁻¹ for recovery at 25%-OBLa and 50%-OBLa, respectively.

Blood $[La^-]$ among the 3 conditions of passive recovery, 25%-OBLa, and 50%-OBLa are shown in Table 1. Across all conditions, there was a significant increase in $[La^-]$ over time. Additionally, the condition by linear trend for the $[La^-]$ interaction was signifi-

Table 2. Ratings of perceived exertion (RPE) prior to, during, and following a resistance training workout employing different recovery conditions ($N = 15$) (mean \pm SEM).*

Condition	Prewarmup	Postset 2	Postrec 2 ^{bc}	Postset 4 ^c	Postrec 4 ^c	Postset 6 ^{ac}	Postrec 6 ^{abc}	Post-MRP set ^c
Passive	0	2.5 \pm 0.3	2.0 \pm 0.2	4.5 \pm 0.4	3.7 \pm 0.3	6.7 \pm 0.3	5.9 \pm 0.3	9.5 \pm 0.1
25%-OBLa†	0	2.4 \pm 0.3	2.0 \pm 0.2	4.2 \pm 0.2	3.6 \pm 0.2	5.8 \pm 0.4	4.9 \pm 0.4	9.3 \pm 0.2
50%-OBLa	0	2.5 \pm 0.3	2.6 \pm 0.3	5.0 \pm 0.3	4.4 \pm 0.3	7.1 \pm 0.3	6.7 \pm 0.4	9.7 \pm 0.2

* Within a measurement, superscript a refers to a significant difference between the passive and 25%-OBLa conditions; superscript b refers to a significant difference between the passive and 50%-OBLa conditions; and superscript c refers to a significant difference between the 25%-OBLa and 50%-OBLa conditions ($p \leq 0.05$).

† OBLa = onset of blood lactate accumulation.

cant, showing that the conditions differed in the rate by which $[La^-]$ increased. No significant mean differences in $[La^-]$ were found in the prewarm-up or postset 2 time points; however, for the other sets and recovery periods, a significant omnibus F -ratio indicated the presence of at least 1 significant difference among the 3 conditions. The most frequent significant difference in $[La^-]$ occurred between the passive and 25%-OBLa conditions, with subjects in the passive condition having the higher $[La^-]$ (Table 1). This was true for $[La^-]$ in postrecovery 2 through the post-MRP time points. Also, for $[La^-]$ in postrecovery 2 through the post-MRP time points, a significant difference occurred between 25%-OBLa and 50%-OBLa conditions, with subjects in the 50%-OBLa condition having the higher $[La^-]$. Only in postset 6, postrecovery 6, and the post-MRP time points did the passive and 50%-OBLa conditions differ significantly (subjects engaged in passive recovery had higher levels of lactate). When engaged in either of the active recovery conditions, especially at 25%-OBLa, subjects tended to have lower lactate levels than when engaged in passive recovery.

Significant differences in RPE among the 3 conditions of passive recovery, 25%-OBLa, and 50%-OBLa are shown in Table 2. Additionally, the condition by linear trend for the RPE interaction was also significant, showing that the conditions differed in the rate by which the RPEs increased. No significant differences in RPE were found between the prewarm-up or postset 2 time points; however, for the other time points, a significant omnibus F -ratio indicated the presence of at least 1 significant difference among the 3 conditions. Significant mean differences in RPE occurred between the passive and 25%-OBLa conditions in postset 6 through the post-MRP time points, with passive recovery showing a higher RPE. Significant mean differences in RPE also occurred between the passive and 50%-OBLa conditions in postrecovery 2 and postrecovery 6, with passive recovery having a lower RPE. Finally, in postrecovery 2 through the postrecovery 6 time points, the RPE for the 25%-OBLa condition was significantly lower than the RPE for the

Table 3. Pearson correlation coefficients for postrecovery 6 $[La^-]$, postrecovery 6 ratings of perceived exertion (RPE), and a maximal repetition performance (MRP) measures following resistance training workouts using 3 different recovery conditions ($N = 15$).

Condition	$[La^-]$ versus RPE	$[La^-]$ versus performance	RPE versus performance
Passive	0.30	-0.72*	-0.22
25%-OBLa†	-0.07	-0.70*	0.05
50%-OBLa	0.46	-0.65*	-0.48

* $p \leq 0.01$.

† OBLa = onset of blood lactate accumulation.

50%-OBLa condition. Thus, the RPE was higher overall for the 50%-OBLa condition, followed by the passive condition, with RPEs lowest for the 25%-OBLa condition.

A significant difference was found in the MRP test. The results of the followup-dependent t -tests indicate that MRP was significantly higher in the 25%-OBLa condition in comparison to the other 2 conditions. There was no significant difference between passive recovery and 50%-OBLa condition. The MRP measures for each of the recovery conditions were as follows: passive (24.1 \pm 1.8 reps), 25%-OBLa (29.3 \pm 1.8 reps), and 50%-OBLa (23.1 \pm 1.7 reps).

Correlation coefficients for postrecovery 6 $[La^-]$, postrecovery 6 RPE, and MRP for each of the 3 recovery conditions are shown in Table 3. A significant, negative correlation was observed between the postrecovery 6 $[La^-]$ and the MRP measure. Not surprisingly, the lower the $[La^-]$ prior to the MRP, the higher the maximal number of repetitions possible. No significant relationships were found in any of the conditions between the postrecovery 6 $[La^-]$ time point and RPE, nor between postrecovery 6 RPE time point and the MRP measure.

Discussion

The primary question in the present study was whether or not active recovery decreased La^- accumulation between sets of parallel squat exercises. The results from the present investigation indicate that lactate accumulation was decreased when low-intensity exercise was employed during the recovery periods between sets (Table 1). The present data reveal that the most effective strategy for decreasing lactate accumulation was to perform active recovery at 25% of the OBLA; recoveries using passive rest and active recovery at 50% of the OBLA were significantly less effective. It also appears that $[\text{La}^-]$ decreases during each recovery period compared to the exercise set just prior to it during the 25%-OBLA condition only (Table 1). The observation that the rate of lactate removal facilitated by the performance of active recovery has been observed previously (8, 9, 21). The data in the present investigation are in agreement with several other studies involving the use of active recovery (1, 11, 24, 29, 30). The blood lactate concentration is a balance between the removal and the production of lactate (2, 4, 8, 9, 14). Alterations in blood $[\text{La}^-]$ during exercise are therefore the net result of the simultaneous, but not necessarily proportional, changes in the production and/or removal of La^- . While the mechanism for enhanced La^- disappearance during active recovery from strenuous exercise is unknown, the oxidation of La^- within the exercising skeletal muscle may be a major mechanism for lactate clearance (9, 30). Gisolfi et al. (9) suggest that the increased clearance rate of La^- during active recovery was probably a result of more rapid distribution of lactate to the liver for oxidation or reconversion to glycogen, increased utilization of lactate by the cardiac muscle, and increased utilization of lactate by active and inactive skeletal muscles.

Another important finding in the present investigation was the high relationship between elevated blood $[\text{La}^-]$ and subsequent exercise performance. As expected, there was an increase in $[\text{La}^-]$ following sets 2, 4, and 6. Moreover, the blood $[\text{La}^-]$ postset 6 differed significantly between conditions and was negatively correlated with the $[\text{La}^-]$ and the maximal repetitions performed (Table 3). These data indicate that subjects with higher $[\text{La}^-]$ performed fewer repetitions on the maximal repetition performance test. These findings are in agreement with previous studies (17, 27), in that work performance is inhibited and muscle fatigue occurs when blood $[\text{La}^-]$ is elevated due to prior exercise. Bogdanis et al. (3) suggest there are at least 4 mechanisms that may explain the performance improvement after active recovery: a greater creatine-phosphate resynthesis; a lower muscle $[\text{La}^-]$ and $[\text{H}^+]$; an increased contribution of aerobic metabolism to energy supply; and nonmetabolic factors. Hermansen and Stensvold (11) observed that an increased activity

of the working muscles would increase the efflux of La^- from the exercising tissue. This increased activity during recovery, especially if it was of low intensity, should enhance performance because of the increased La^- and H^+ efflux from the working muscles and decreased intracellular $[\text{H}^+]$. This increased activity during recovery should allow the working tissues to continue performing in an optimal cellular environment.

Failure to consider the individual differences for an optimal recovery exercise intensity with respect to each subject's OBLA could possibly shift the balance to a greater production of lactate. In the present study, in order to precipitate an optimal lactate elimination response, individual OBLA were determined using a GXT. According to Heck et al. (10), a maximal steady state was found at a lactate value of $4.02 \text{ mmol}\cdot\text{L}^{-1}$. By observing the exercise intensity at the $4.0 \text{ mmol}\cdot\text{L}^{-1}$ blood $[\text{La}^-]$, we were able to individualize each subject's recovery intensities. The power outputs used in the current study were $\sim 46 \text{ W}$ and $\sim 74 \text{ W}$ for 25%-OBLA and 50%-OBLA, respectively. These values, relative to the OBLA, are within the previously reported optimal values for active recovery (2, 4, 8). At exercise intensities greater than the OBLA, there will be an imbalance between the rates of La^- production and clearance, and as a result, La^- will progressively accumulate in the blood (16). Therefore, if the OBLA of an athlete is evaluated, and the resulting information is to be applied to the training regime, an effective and safe means to performance enhancement can be produced.

A finding of interest in this investigation is the variation of significant mean differences in RPE throughout the workout sets. As indicated in Table 2, significant differences in RPE occurred between the passive and 25%-OBLA conditions in postset 6 through post-MRP time points and between the passive and 50%-OBLA conditions in postset 3 and post-recovery 6. Additionally, in postrecovery 2 through postrecovery 6, the RPE for the 25%-OBLA condition was significantly lower than the RPE for the 50%-OBLA condition. Thus, the RPE was higher overall for the 50%-OBLA condition. These data indicate a reduced perception of effort during exercise at lower intensity compared to passive and higher intensity recovery. Although there were significant differences between the recovery conditions, no significant correlations were observed between postrecovery 6 RPE and MRP within each of the 3 recovery conditions.

In summary, the present study demonstrated that lower-intensity active recovery effectively minimized La^- accumulation compared to passive or higher-intensity active recovery. The data strongly support the view that the elimination of La^- occurs using low-intensity active recovery following intense resistance exercise and is associated with improved endurance performance in the squat exercise.

Practical Applications

When attempting to improve large muscle resistance training performance an active recovery between sets should be used. The improvement in performance is likely due to a decrease in lactate accumulation during recovery. Based on the data from this investigation it appears that exercise at 25% of the power elicited at a blood lactate concentration of 4.0 mmol·L⁻¹ is better than passive recovery or exercise at 50% of the power elicited at a 4.0 mmol·L⁻¹ blood lactate concentration. Strength and conditioning professionals and athletes should identify this exercise intensity through testing and then incorporate an active recovery scheme into their training workout.

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