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Review Article

Gender Differences in Peak Blood Lactate Concentration and Lactate Removal

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Abstract

Anaerobic exercise induces accumulation of lactate, which may cause muscular fatigue. Consequently, lactate removal during recovery may be critical for resumption of exercise, especially during athletic competition. The purpose of the study was to compare gender differences in peak blood lactate concentration and removal rate following strenuous exercise. Untrained, physically active male (n=17) and female (n=17) college students (23.4 + 2.8 yrs) were used as subjects. Subjects performed a treadmill test to determine their maximal oxygen consumption (VO2max) and obtain peak blood lactate concentrations at 5 min post-exercise. Immediately thereafter, subjects performed an active recovery on a treadmill at 40% VO2max for 30 min for determination of lactate removal. Blood samples were taken at rest, 5th min of sitting recovery following a treadmill VO2 max test, and at 5th, 10th, 15th, 20th, and 30th min of 30 min active recovery at 40% VO2max. There were no significant gender differences in resting and peak blood lactate concentrations. There was no gender difference in blood lactate removal at any time point during the active recovery period. During active recovery, the largest and the smallest percentages of blood lactate removed were observed between 5 to 10 min, and 20 to 30 min, respectively. Nearly 80% of the lactate was removed by the end of 30 min recovery period. These data show that untrained young men and women have similar resting and peak blood lactate concentrations, and no differences in the rate of blood lactate removal during active recovery from a strenuous exercise.

INTRODUCTION

An accumulation of lactate occurs when one is not able to meet the energy demand of exercise by aerobic metabolism. Lactic acid produced in skeletal muscle during exercise diffuses into the blood. Blood lactate concentration represents the difference between release of lactate into blood from contracting skeletal muscle and the removal (uptake) of lactate by various tissues, including the liver [1], heart muscle [2], and skeletal muscle [3, 4]. The accumulation of lactate in the blood is believed to represent an increased reliance on glycolytic pathways for energy production, and a subsequently faster rate of lactate diffusion into blood compared with removal from blood [5]. Lactic acid dissociates readily resulting in lactate, the salt of the acid, plus a hydrogen ion (H^+).An increased lactic acid production, therefore, results in increased H^+ release and a subsequent decrease in muscle pH [6]. A decrease in muscle pH limits the production of energy through anaerobic glycolysis by the inhibition of the rate limiting enzymes phosphofructokinase [7] and phosphorylase [8].

Gollnick and Hermansen [9] have shown that muscle fatigue is associated with blood lactate concentrations usually between 60 and 200mg%. Thus, lactate appears to cause muscular fatigue indirectly by decreasing the intracellular pH of muscle. High level of blood lactate induces in low athletic performance [10]. Consequently, lactate accumulation during exercise and removal during recovery may be critical for resumption of exercise, especially during athletic competition.

In general, compared to women, men possess larger muscle mass, higher hemoglobin concentration, more blood volume, and higher maximal oxygen consumption (VO_2max) [11]. These differences may lead to the speculation on gender differences in lactate production during strenuous exercise and lactate removal during recovery. However, gender differences in peak lactate concentration and lactate removal have not been systematically studied. Conflicting results have been reported from research on gender differences related to lactate metabolism. Froberg and Pedersen [12], Lehmann et al., [13], and Ohkuwa, Miyamura, Andou, and Utsuno [14] found no differences in resting and peak blood lactate concentration between untrained men and women after exercise at submaximal and maximal intensities. However,

Komi and Karlsson [15] reported that the lactate concentration in untrained men was higher than in untrained women following a maximal treadmill running test. Costill , Fink, Getchell , Ivy, and Witzmann [16] found that the blood lactate concentration was higher in trained female runners than in trained male runners after 30 and 60 min of submaximal exercise (70% VO_2max).

Numerous researchers have examined lactate removal after strenuous exercise. The rate of removal of lactate from the blood was accelerated up to about two fold by performance of light aerobic exercise during the recovery period [17, 18]. The elimination of lactate from the blood following exhaustive work appears to be due to an increased blood flow and more rapid transportation of lactate to the liver for resyntheses of glycogen and the oxidation of lactate to CO_2 and water in the working muscles [19, 20]. Several researchers have found that the optimal intensity for blood lactate removal during recovery exercise approximates 40 to 60%VO_2max [18, 21-23]. Results from studies comparing gender differences in blood lactate accumulation are limited and equivocal, and no studies were found where the researchers specifically examined gender differences in blood lactate removal after strenuous exercise. Therefore, the purpose of the present study was to compare gender differences in peak blood lactate concentration and removal rate following strenuous exercise.

METHODS

Subjects

Subjects for this study were physically active untrained college volunteers (men, n=17; women n=17), 19 to 28 years of age. All subjects signed a written informed consent approved by the Institutional Review Board. Subjects were screened for physical activity and body fatness before selection. Forty five subjects volunteered but only 34 of them met the healthy (medical questionnaire) untrained, but active, non-obese criteria (less than 30% fat for women, less than 19% fat for men). Based on a self-reported physical activity survey, the subjects engaged in light to moderate aerobic exercise for 90 to 120 min per week. All female subjects had regular menstrual cycles.

Values are expressed as mean + SD; HR, heart rate; NS, not significant ($p > 0.05$).

Experimental Procedures

The subjects were asked to maintain their usual diet during the three days before testing and to refrain from strenuous exercise for 48 hours prior to testing. No food intake was allowed for 3 hour prior to testing. Upon reporting to the laboratory, the subjects were measured for height (Ht), weight (Wt), skin folds, resting heart rate (HR) (5 min), and resting oxygen uptake (5 min). A resting blood sample was taken for lactate analysis. Subjects performed a treadmill test to determine their VO_2max and obtain peak blood lactate concentrations at 5 min post-exercise sitting at rest. Immediately thereafter, subjects performed an active recovery by walking on a treadmill at 40% VO_2max for 30 min for determination of lactate removal. The mean values of triplicate skin fold measurements was used to estimate body density using the equations described for men and women, respectively [24]. Percent body fat was determined from the Siri equation [25] .

Oxygen uptake measurements

Oxygen uptake measurements were made using a Sensormedics-2900 metabolic cart (Sensormedics Co, Ahaheim, CA). A progressive, continuous treadmill test was utilized to assess VO_2max, obtain maximal effort exercise for peak blood lactate concentration, and determine the work load at 40% VO_2max for each subject. Following warm-up (3 min at 3.0 mph, 0% grade for men, and 2.0 mph, 0% grade for women), the treadmill speed was increased by 1 mph (0% grade) every 3 min, up to 4 mph for women and 5 mph for men. Thereafter, speed was increased by 1 mph (0% grade) every 2 min up to 6 mph for women and 7 mph for men. The grade was then increased by 2% every 2 min (speed constant) until the subject was exhausted. The criteria used for the determination of VO_2max were a plateau in VO_2 (increase of less 2 $ml \cdot kg^{-1} \cdot min^{-1}$) and a respiratory exchange ratio (RER) of greater than 1.1 during the final stage of exercise. Oxygen uptake was measured and respiratory exchange ratio was calculated for each minute of rest, the VO_2max test, and recovery (5 min sitting and 30 active recovery). Heart rate was monitored continuously and the mean of the last 15 s of each min was recorded. Values obtained during the last minute (near steady state) of each exercise intensity were used to represent that workload.

Immediately following the VO_2max test, the subject sat in a chair for 5 min, and then performed an active recovery test at 40% VO_2max for 30 min. VO_2 was measure every minute of active recovery to verify the exercise intensity of 40% VO_2max. If VO_2exceeded +5% from the desired intensity 5 min after the recovery test started, the treadmill speed was adjusted accordingly. The mean VO_2 and mean heart rate values from the last 25 min were used to determine the actual percentage of VO_2max and HR during the active recovery period.

Blood lactate measurement

Puncture blood samples were collected into heparinized capillary tubes at the 5th min (sitting rest) after the VO_2max test and during the active recovery test (at the 5th, 10th, 15th, 20th, and 30th min). Blood samples were immediately transferred into tubes containing 50 µl of lactate buffer, Triton X-100, and sodium fluoride. Lactate concentrations were measured within 2 hours after the blood sample was obtained using an YSI model 23L L-Lactate analyzer (Yellow Springs Instrument Co., Yellow Springs, OH). Duplicate measurements were taken for each sample, and the mean value for the duplicate samples was used in analysis. The test-retest reliability of duplicate samples yielded a correlation coefficient of r=0.998.

Blood lactate removal rate (LaRR%) during the 30 min active recovery period was calculated using the following formula:

$$LaRR\% = (P - S1\text{-}5) / (P - R) \times 100,$$

Where P is peak lactate concentration, S1-5 represents each of the lactate concentrations from the five recovery blood samples, and R is resting blood lactate concentration. LaRR% represent the percentage of blood lactate removed at each given time point relative to the peak concentration.

The percentage of blood lactate removed within each time segment (difference between two adjoined removal rates) was also calculated to identify possible differences in lactate removal

among the five time segments (0-5, 5-10, 10-15, 15-21, and 20-30 min) during active recovery. These percentages reflected percentage of the total lactate removed within a given time segment.

Statistical analysis

Group's t-tests were used to determine gender differences in physical characteristics examined. A two-way ANOVA with repeated measures was used to detect the variations in the experimental parameters. A Newman-Keuls teat was used for multiple comparisons if there was a significant time effect. The accepted level of significance for this study was $p < 0.05$.

RESULTS

The descriptive statistics for the physical characteristics of the subjects are presented in (Table 1). The mean height, weight, and VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$) of the men were significantly ($p < 0.05$) higher than that of the women. The percent body fat was significantly ($p<0.05$) higher in the women than in the men. When expressed as oxygen consumption to free fat weight ($ml \cdot kg\ FFW^{-1} \cdot min^{-1}$), the mean$VO_2$max of the men was not significantly different from the women. There were no significant gender differences in age, age, HRmax, recovery VO_2 (last 25 min), and recovery HR (last 25 min).

Figure (1) depicts blood lactate concentrations and removal patterns for men and women. No significant ($p > 0.84$) gender differences were found in the mean blood lactate concentrations at rest, peak, or at any of the recovery times. All mean blood lactate concentrations at a given time point were significantly ($p < 0.05$) different from each other except for rest vs. min 30 min values. The blood lactate removal rate (LaRR %) within each time segment during active recovery are depicted in Figure (2). No significant ($p = 0.39$) gender differences were found in

Table 1: Physical Characteristic of Subjects.

Variables	Men (n= 17)	Women (n= 17)	P value
Age (yr)	23.7 ± 2.9	23.2 ± 2.7	NS
Height (cm)	176.0 ± 5.6	161.0 ± 6.6	<0.05
Weight (kg)	74.7 ± 9.6	58.8 ± 5.5	<0.05
Fat (%)	13.3 ± 4.3	22.3 ± 5.6	<0.05
HRmax ($b \cdot min^{-1}$)	196.0 ± 9.9	191.2 ± 12.3	NS
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	50.9 ± 3.2	44.6 ± 4.2	<0.05
VO_2max ($ml \cdot kg\ FFW^{-1} \cdot min^{-1}$)	56.7 ± 3.1	57.5 ± 4.8	**NS**
Recovery %VO_2max	38.9 ± 1.1	38.9 ± 0.9	NS
Recovery HR ($b \cdot min^{-1}$)	142.4 ± 9.5	141.7 ± 15.0	NS

Values are expressed as mean ± SD; HR, heart rate; NS, not significant ($p > 0.05$).

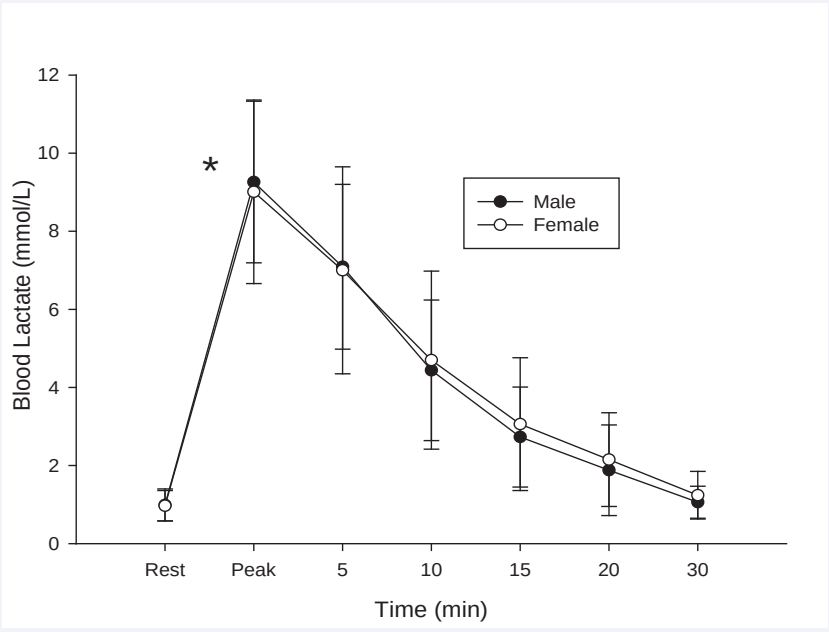

Figure 1 Blood Lactate concentrations and removal patterns for men and women.

No significant ($p = 0.84$) gender differences were found in the mean blood lactate concentrations at rest, peak, or at any of the recovery times. *All mean blood lactate concentrations at a given time point were significantly ($p < 0.05$) different from each other except for rest vs. min 30 min values.

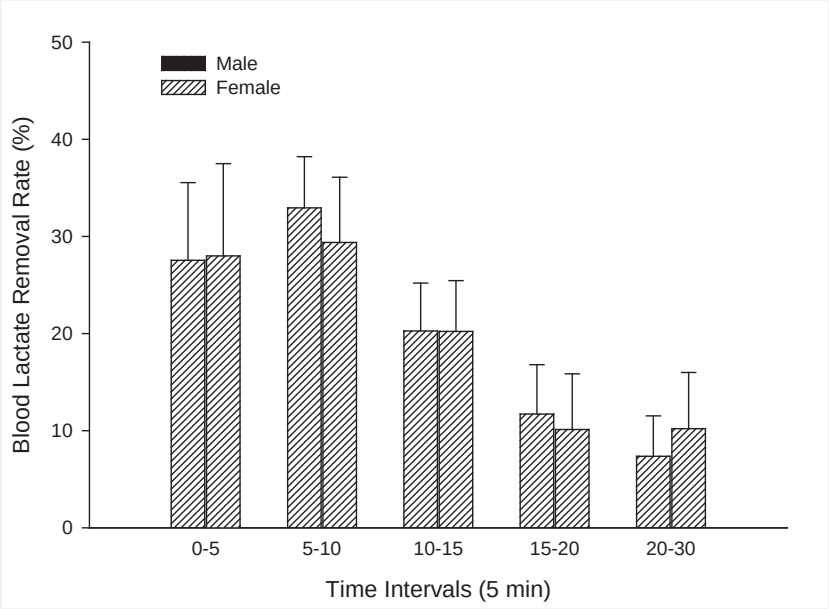

Figure 2 Blood Lactate removal rate within each time segment during active recovery for men and women.

No significant (p = 0.39) gender differences were found in blood lactate removal within each time segment during the active recovery period. When time segments were compared for the percentages of lactate removed, there were significant (p < 0.05) mean differences in blood lactate removal among the five different time segments except between the 0-5 min and 5-10 min periods.

blood lactate removal within each time segment during the active recovery period. When time segments were compared for the percentages of lactate removed, there were significant (p < 0.05) mean differences in blood lactate removal among the five different time segments except between the 0-5 min and 5-10 min periods. The largest and the smallest percentage of blood lactate removed were observed between 2 to 10 min, and 20 to 30 min, respectively.

DISCUSSION

The principal findings of this study were that the blood lactate concentrations of the untrained men and women were not different at rest, at peak, nor during 30 min of active recovery at 40% VO_2max. Secondly, the lactate removal rates during active recovery (40% VO_2max) did not differ between men and women.

The male and female subjects used in this study had similar physical fitness levels identified from their physical activity histories and their VO_2max expressed as ml·kg FFW^{-1}·min^{-1} (Table 1). The difference (12% higher for men) inVO_2max expressed as ml·kg^{-1}·min^{-1} for the men and the women in the present study can be explained by the fact that the women had a significantly higher percent body fat than the men [26]. The similar physical fitness levels (expressed as VO_2max to free fat weight) of the male and female subjects may explain the lack of gender differences in peak blood lactate concentration and lactate removal rates.

Blood Lactate concentrations

The mean values of resting blood lactate concentrations (0.99 + 0.41 vs 0.97 + 0.39 mmol·l^{-1} for men and women, respectively) in the present study were similar to those reported by Lehmann et al., [13] who reported no gender difference in resting blood lactate concentration (1.43 ± 0.2 and 0.97± 0.2 mmol·l^{-1} for men and women, respectively). The peak blood lactate values (9.26 + 2.0 vs. 9.01 + 2.3 mmol·l^{-1} for men and women, respectively) from the present study were also compatible with the results from a study by Fro berg and Pedersen [12]. They reported that men and women had similar peak blood lactate concentration. Similarly, Lehmann et al., [13] also reported that there was no difference in peak lactate concentrations between men and women (10.3 ± 2.2vs. 10.8± 1.5 mmol·l^{-1}).

Because skeletal muscle is the major source of lactate production during strenuous exercise [27], and the men had more muscle mass than the women, it might be expected that men could produce more lactate and might have higher peak blood lactate concentration. There is some evidence, however, that women have higher plasma epinephrine concentrations during strenuous exercise [13]. Epinephrine stimulates glycogenolysis and, therefore, may enhance lactate production. Thus, the women could have had a higher blood epinephrine concentration during strenuous exercise which might help compensate for a lower lactate production from their smaller muscle mass. Since epinephrine concentration was not measured in this study, however, this explanation is only hypothetical.

Another possible explanation for the similar peak blood lactate values between men and women in this study may be that blood lactate concentration is affected not only by the lactate diffusion into the blood but also by the blood volume into which it diffuses. Because women have a smaller total blood volume (4.0 to 4.5 l) than men (5.0 to 6.0 l) [28], a smaller amount of lactate would be required to produce a similar blood lactate concentration.

The female subjects in this study had almost twice the percent body fat as the male subjects (22.3% vs. 13.3%).

Significant lactate production from glucose has been found in adipose tissue [29, 30]. Hagstrom et al., [29] reported that the maximum lactate concentration in subcutaneous adipose tissue was 30% higher than that in blood plasma after oral glucose ingestion. Following glucose ingestion, the glucose taken up by adipose tissue was 10-20% of the total body glucose uptake [31] and the glucose taken up by adipose tissue was partly converted to lactate [29, 30]. Because blood glucose concentration typically increases during short-term strenuous exercise [32, 33] greater glucose uptake may occur in adipose tissue even though there is not an increased need for additional glucose for reformation of triglycerides. Under such conditions, some of the glucose taken up by adipose tissue might be converted to lactate. However, it is not known whether the high percent fat in women influences lactate entering blood from adipose tissue during exercise.

Although women have less muscle mass than men, and skeletal muscle is the major contributor to blood lactate concentration, their similar free fat weight VO_2max (ml·kg FFW^{-1}·min^{-1}) to men, higher percentage of adipose of adipose tissue, expected smaller blood volume, and possibly higher blood epinephrine concentration might compensate for the smaller total amount of lactate produced from their smaller muscle mass and, thus, account for a peak blood lactate concentration similar to that of men.

Blood Lactate removal rate

Lactate produced during anaerobic exercise can be removed during aerobic exercise and recovery through the Cori cycle [1]. In Cori cycle, lactate is transported via blood to the liver where it is converted back to glucose, which either can be transported back to the muscles or stored as glycogen in the liver [1]. In addition, cardiac muscles [34] and slow twitch muscle fibers [35] are another major sources for lactate removal, where lactate is converted to pyruvate and acetyl-CoA to be oxidized in the Krebs cycle.

After 30 min of active recovery at 40% VO_2max, 99.6% and 98.0% of the blood lactate were removed for the men and women, respectively. This finding supports the previous observations on men by Belcastro and Bonen [17], and Stanford at al., [21]. The lactate removal rates of the male subjects in the present study were similar to those of the female subjects at each of the five measurement times during the active recovery period. Because blood lactate can be removed by well oxygenated skeletal muscles [36,37] the similar levels of aerobic fitness relative to free fat body mass may explain why the blood lactate removal rates of men and women were not different. Furthermore, both groups exercised at the same percentage (about 40%) of VO2max during the recovery period, an exercise intensity at which skeletal muscle is expected to be well oxygenated.

Another factor which could help women remove lactate at a rate similar to men, despite their smaller muscle mass, is a higher plasma concentration of EPI for women during strenuous exercise [13]. If plasma EPI concentrations were higher in these women, they could have a faster rate of glycogenolysis and a greater glycogen decrease during exercise. Since skeletal muscle with lower glycogen content can take up more lactate [37, 38]. It is possible that if the female subjects had relatively lower glycogen concentration, they could remove blood lactate faster during recovery, which would help compensate for their smaller muscle mass. The extent to which skeletal muscle glycogen decrease occurs during a maximal effort test, however, would be small. Consequently, any gender differences in glycogen depletion would be small with the short term, strenuous exercise in this study. Because the muscle glycogen levels were not measured in the present study, the contribution of a lower skeletal muscle glycogen concentration to blood lactate removal is hypothetical.

In the present study, the mean heart rate during the active recovery was 74% of the maximal heart rate. Since nearly 80% of the blood lactate was removed within 15 min and almost 100% of the lactate was removed by the end of the 30 min active recovery period, it is suggested that an untrained individual can have a rapid removal of lactate from blood with a warm down at about 70 to 75% of his or her maximal heart rate following strenuous exercise.

In conclusion, our data showed no gender differences in resting or peak blood lactate concentrations, nor in the rate of blood lactate removal of young adult men and women with similar aerobic fitness level expressed as ml·kg FFW^{1}·min^{-1}. Exercise at 70 to 75% of the maximal heart rate may be desirable recovery intensity for effective blood lactate removal following maximal effort exercise for physically active untrained young adult men and women. Additional studies including measurements of muscle fiber composition, LDH activity, and concentrations of EPI, blood glucose, and muscle glycogen are needed to identify more clearly the similarities or differences in lactate metabolism between men and women.

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