**Blood lactate exchange and removal abilities after relative high-intensity exercise: effects of training in normoxia and hypoxia**

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**Abstract** The effects of 4 weeks of endurance training in conditions of normoxia or hypoxia on muscle characteristics and blood lactate responses after a 5-min constant-load exercise (CLE) at 90% of the power corresponding to the maximal oxygen uptake were examined at sea-level in 13 sedentary subjects. Five subjects trained in normobaric hypoxia (HT group, fraction of oxygen in inspired gas = 13.2%), and eight subjects trained in normoxia at the same relative work rates (NT group). The blood lactate recovery curves from the CLE were fitted to a biexponential time function:

\[ \text{La}(t) = \text{La}(0) + A_1 (1 - e^{-\gamma_1 t}) + A_2 (1 - e^{-\gamma_2 t}) \]

where the velocity constants \(\gamma_1\) and \(\gamma_2\) denote the lactate exchange and removal abilities, respectively, \(A_1\) and \(A_2\) are concentration parameters that describe the amplitudes of concentration variations in the space represented by the arterial blood, \(\text{La}(0)\) is the lactate concentration at time \(t\), and \(\text{La}(0)\) is the lactate concentration at the beginning of recovery from CLE. Before training, the two groups displayed the same muscle characteristics, blood lactate kinetics after CLE, and \(\gamma_1\) and \(\gamma_2\) values. Training modified their muscle characteristics, blood lactate kinetics and the parameters of the fits in the same direction, and proportions among the HT and the NT subjects. Endurance training increased significantly the capillary density (by 31%), citrate synthase activity (by 48%) and H isozyme proportion of lactate dehydrogenase (by 24%), and \(\gamma_1\) (by 68%) and \(\gamma_2\) (by 47%) values. It was concluded that (1) endurance training improves the lactate exchange and removal abilities estimated during recovery from exercises performed at the same relative work rate, and (2) training in normobaric hypoxia results in similar effects on lactate exchange and removal abilities to training in normoxia performed at the same relative work rates. These results, which were obtained non-invasively in vivo in humans during recovery from CLE, are comparable to those obtained in vitro or by invasive methods during exercise and subsequent recovery.

**Keywords** Humans · Recovery · Normoxia · Normobaric hypoxia · Longitudinal study

**Introduction**

It has been shown that capillarization (Tesch and Wright 1983) and carrier-mediated lactate transport (Juel 1997), which are two of the determining factors of lactate release from exercising muscles to the blood, are significantly improved by training (Ingjer 1979;...
Pilegaard et al. 1999; Dubouchaud et al. 2000). However, the effects of training on the lactate exchange processes between the active muscles and the blood deserve further in vivo exploration in humans. From a conceptual point of view, it can reasonably be assumed that after high-intensity muscular exercises, the net lactate release rate from the muscles involved in the exercise to the blood depends not only on the lactate gradient, but also on the efficiency with which lactate is released. The velocity constants $\gamma_1$ and $\gamma_2$ of the biexponential time function fitted to the arterial lactate recovery curves obtained after muscular exercise have been shown to supply information on the lactate exchange ability between the previously active muscles and the blood ($\gamma_1$) as well as on the body’s overall ability to remove lactate ($\gamma_2$) during the recovery (Freund et al. 1986; Freund and Zouloumian 1981). So far, this approach has not been applied in a longitudinal study that has been designed to investigate the effect of training on lactate exchange ability.

Studies on the influence of training on the lactate removal processes have provided differing results. According to Bassett et al. (1991), the training affects neither the pattern of blood lactate decline nor the lactate removal ability ($\gamma_2$) during recovery after 3 min of exercise at $\approx 85\%$ of maximum oxygen uptake ($\dot{V}O_{2\text{max}}$). These results conflict with those obtained by MacRae et al. (1992), whose study involved the use of tracers during exercise. Specifically, these authors observed, during incremental exercises (IE) leading to $\approx 75\%$ of $\dot{V}O_{2\text{max}}$, lower blood lactate concentrations after 9 weeks of endurance training, and attributed this decrease to the training-induced elevation of the lactate metabolic clearance rate (MCR). The results of Bassett et al. (1991) also contrast with a recent study of Messonnier et al. (1997), who found a positive correlation among high level oarsmen between the relative work rate corresponding to the 4 mmolL$^{-1}$ blood lactate concentration obtained during an IE (anaerobic threshold) and the recovery lactate removal ability. In view of these opposing results, the effect of training on the lactate removal ability during recovery from high-intensity exercises performed at the same relative work rate before and after training deserves to be re-examined.

A number of coaches and athletes remain convinced that moderate-altitude training is more effective than normoxic training for improving the physical aptitude at sea level. Previous studies have already investigated the effects of acute and chronic hypoxia on lactate kinetics (Brooks et al. 1992, 1998). However, no study has compared the effects of training in hypoxia and in normoxia on the sea-level lactate exchange and removal abilities. If the potentiating effect of hypoxia during training on the lactate exchange and removal abilities can be proved, the information would be of interest for the coaches of athletes involved in endurance events. Indeed, it has been shown that the better performance during a 2500-m all-out rowing test lasting for more than 7.5 min is associated with better lactate exchange and removal abilities (Messonnier et al. 1997).

Thus, we performed experiments in a population of sedentary subjects to compare the effects of 4 weeks of endurance training, conducted at the same relative work rates in conditions of normoxia and in normobaric hypoxia, on the sea-level lactate exchange and removal abilities during recovery from muscular exercise. In view of the paucity of data on the in vivo lactate exchange ability in humans and the conflicting results obtained by previous authors for lactate removal, another aim was to examine whether endurance training would improve these dynamic parameters during recovery from short-duration, high-intensity exercises performed at the same relative work rate before and after training.

### Methods

#### Subjects

Thirteen healthy subjects (three females and ten males) participated in the study. Their mean (SE) age, body mass and height were 20.5 (0.5) years, 70 (5) kg and 175 (3) cm, respectively. Before giving their written consent to participate, they were informed of the nature, the potential risks involved and the benefits of the study. The experiments received the approval of the Ethical Committee on Human Research of the institution involved, at Saint-Etienne.

#### Experimental design

Two weeks before the start of the experiments, all of the subjects were submitted to an inclusion protocol. This consisted of a physical examination, anthropometric measurements and an IE up to exhaustion that allowed the subjects to become accustomed to the equipment and testing procedures. All of the exercise tests were performed in the upright position using a bicycle ergometer (Monark 818E, Stockholm, Sweden). The instantaneous power output and the pedaling frequency (set at 75 rpm) were delivered on-line by a computer device that was developed in the laboratory. The experiments and training sessions were conducted either in normoxia (inspired partial pressure of oxygen, $P_{O_2} = 141$ mmHg, 18.8 kPa) or in normobaric hypoxia ($P_{O_2} = 89$ mmHg, 11.9 kPa). The protocol consisted of pre-training, training and post-training periods.

#### Pre-training period

This involved three experimental sessions separated by at least 2 days.

#### Session 1: IE test up to exhaustion in normoxia

The test began with a 2-min rest period on the ergometer, followed by 2 min of warm-up cycling at 0 W. The work rate was then set at 60 W for the men and 40 W for the women. After 2 min of cycling at this load, the work rate was incremented every 2 min by 30 W for the males and 20 W for the females. This procedure was continued until exhaustion, which was defined as the point at which the subjects could no longer maintain the requested pedaling frequency. Expired gas samples were analyzed continuously for oxygen uptake ($\dot{V}O_2$) measurement. Capillary blood samples were collected from the fingertip prior to the exercise and during the last 20 s of each exercise step, for the determination of the arterialized blood lactate concentration. This session was carried out to estimate the maximal oxygen uptake ($\dot{V}O_{2\text{max}}$, 1 min$^{-1}$), the corre-