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RELATIONSHIP BETWEEN EMG, BLOOD LACTATE, AND PLASMA CATECHOLAMINE THRESHOLDS DURING GRADED EXERCISE IN MEN

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The aim of this study was to follow up the electromyographic activity (EMG) of dynamically working muscles with simultaneous determinations of blood lactate and plasma catecholamine concentrations during progressive exercise. Twenty eight male soccer players aged 20.6 ± 0.8 yrs performed incremental bicycle ergometer exercise test. The test consisted of 3-min stages exercise separated by 1-min rest intervals. Work load at each stage increased by 50 W until volitional exhaustion. The root mean square (rms)-EMG activity of the rectus femoris and soleus muscles were recorded continuously during exercise. Venous blood samples were taken after each exercise stage for determination of blood lactate (LA). Additionally in seven subjects adrenaline (A) and noradrenaline (NA) concentrations were determined. The EMG activity increased negligibly during exercise of low to moderate intensities revealing an abrupt rise at the load corresponding to thresholds of blood lactate and plasma catecholamine accumulation (LA-T, A-T, NA-T). Close correlations ($P < 0.001$) were found between blood LA concentrations and EMG derived from rectus f. ($r = 0.72$) and soleus ($r = 0.68$) muscles. The mean threshold exercise intensities for m. rectus f. and m. soleus EMG (176 ± 9 W and 172 ± 9 W, respectively) did not differ significantly from lactate (164 ± 7 W), noradrenaline (178 ± 6 W) and adrenaline (180 ± 5 W) thresholds, all of them detected by log-log transformation. The results indicate that threshold character of EMG changes in dynamically working muscles reflects to some extent the patterns of blood lactate and plasma catecholamine changes during incremental exercise.

Key words: EMG, blood lactate, plasma catecholamines, progressive exercise, anaerobic threshold.

INTRODUCTION

It has been well documented that both blood lactate and plasma catecholamine concentrations show an exponential increase during an incremental exercise, with a threshold rise at similar submaximal exercise intensities between 50 and 75% of maximal oxygen consumption (VO_{2max})

(1—5). Moreover, close correlations have been reported between lactate (LA) and plasma adrenaline (A) or noradrenaline (NA) concentrations during progressive exercise (1, 5, 6, 7).

It suggests a contribution of the sympatho-adrenal system to the mechanisms of anaerobic threshold (AT) but the causal relationship between AT and accompanying changes in plasma catecholamines still remains a matter of discussion (5, 8, 9).

One possible physiological explanation of the AT focuses on the pattern of the muscle fiber recruitment during graded exercise (10). Since 1980, when Moritani and De Vries (11) have reported that the onset of nonlinear increase in electromyographic activity (EMG) during progressive exercise occurs at the AT, it has been postulated that the rapid recruitment of fast-twitch (FT) fibers may potentiate lactate production and its accumulation in muscles and blood (12, 13). However, the question remains, whether the rapid rise in FT fiber recruitment is primary or subsequent to the threshold accumulation of lactate, or catecholamines, during progressive exercise.

The present study was designed to investigate relationships between the changes in the electrical activity of dynamically working muscle groups with different morphological characteristics (soleus vs rectus femoris muscle), blood lactate and plasma catecholamine concentrations during graded exercise and to find out what is the sequence of those three: EMG, catecholamine and lactate thresholds.

MATERIAL AND METHODS

Subjects

Twenty eight male soccer players volunteered for this study. The subjects' age ranged from 18 to 28 yrs. All of them had been involved in regular training program for several years (8.4 ± 0.7 yrs). Basic anthropometric characteristics and some maximal exercise data are presented in Table 1. Details of the risks, benefits and experimental procedure of the study were provided for each subject before obtaining his written informed consent.

Table 1. Descriptive characteristics of subjects ($n = 28$).
 VO_{2max} — maximal oxygen consumption, HRmax — maximal heart rate

Age (yrs)	20.6 + 0.8
Body mass (kg)	73.2 + 1.3
Height (cm)	179.0 + 0.93
VO_{2max} ($l \cdot min^{-1}$)	4.04 + 0.12
HRmax (beats $\cdot min^{-1}$)	187.8 + 1.8
Maximal Power Output (W)	308.9 + 4.5

Values are expressed as means + SE.

Experimental protocol

Exercise tests were conducted in a sitting position on an electronically braked bicycle ergometer (EM 840, Siemens, Germany). The 3-min exercise loads were increased by 50W until volitional exhaustion starting from 50 W. The work loads were separated by 60 s recovery intervals for blood sampling.

Respiratory gas exchange was analyzed continuously and computed every 30 s during the incremental test with an Cardiopulmonary Exercise System CPX (Med Graphics TM, USA). The VO_2 „levelling off” criterion was used to establish the maximum oxygen uptake. Heart rate (HR) was measured using Sport Tester (PE 3000, Oulu, Finland).

Venous blood samples for lactate (LA) determinations were taken from an antecubital vein *via* the previously inserted catheter after each 3-min exercise stage and immediately after cessation of the maximum exercise. Blood LA concentration was determined according to the enzymatic method of Gutmann and Wahlefeld (14) using commercial kits (Boehringer, Mannheim, Germany). Additional blood samples were drawn from 7 subjects, at the same time points, for catecholamine determinations. Plasma noradrenaline (NA) and adrenaline (A) concentrations were measured by the radio-enzymatic method of Da Prada and Zurcher (15) with kits purchased from Chemapol Co. Ltd. (Czech Republic). The analytical error of this method is 10.8% for adrenaline, and 8.7% for noradrenaline concentrations.

Blood lactate threshold (LA-T) was detected for each individual using a log-log transformation method, i.e. the bi-segmental logarithmic model of Beaver *et al.* (16). As has been reported by Robergs *et al.* (17) there is no significant difference between LA-T detected by this method based on lactate concentration in venous and arterialized blood, despite the differing absolute lactate concentrations between the two blood compartments. The threshold workload was assessed from the intersection of the two linear segments (log LA plotted vs log work load) and expressed also in relation to minute oxygen consumption (VO_2) and HR, as well as to the percentage of maximal work load (WL), VO_2 and HR. The values of VO_2 and HR corresponding to LA-T were calculated by means of an interpolation from the linear regression of VO_2 or HR vs WL. The catecholamine thresholds (NA-T and A-T) were detected using the log-log transformation similarly as in the case of LA-T.

The electromyographic activity (EMG) was simultaneously recorded from the rectus femoris and soleus muscles. Myoelectric signals were recorded by means of monopolar technique using surface electrodes (Medicotest Q-00-1-, Denmark) attached over the muscle bellies after careful cleaning of the skin. In case of the soleus muscle, localized not so superficially as other muscles, the active electrode was fixed at the carefully chosen part of the calf, where the soleus muscle is covered only by the electrically neutral ligament of the gastrocnemius. The myoelectrical activity was assessed using the EM-10 RI EMG-analyser (Mega Electronics Ltd., Kuopio, Finland) which fully rectifies and integrates the 20–500 Hz band and gives a root mean square of raw EMG signals (rms-EMG). The EMG signals were processed by the EMG device with a time constant of 120 ms (Remes *et al.* 1984).

Statistical Analysis

Statistical significance of differences between the means was tested with an analysis of variance followed by the Student's test. Significance was set at the 0.05 level of confidence. All data are reported as means \pm SE.

RESULTS

The rms-EMG activity recorded from the rectus femoris and soleus muscles during incremental exercise, as well as A and NA concentrations, started to rise immediately after the beginning of exercise and then increased gradually with increasing work intensity until exhaustion, revealing the exponential increase similar as blood lactate concentration (*Fig. 1* and *Fig. 2*). The ms-EMG activity derived from rectus femoris and soleus muscles correlated significantly ($P < 0.01$) with blood lactate concentrations during incremental exercise (*Fig. 3*). However, only slight increases in EMG were found during exercise of

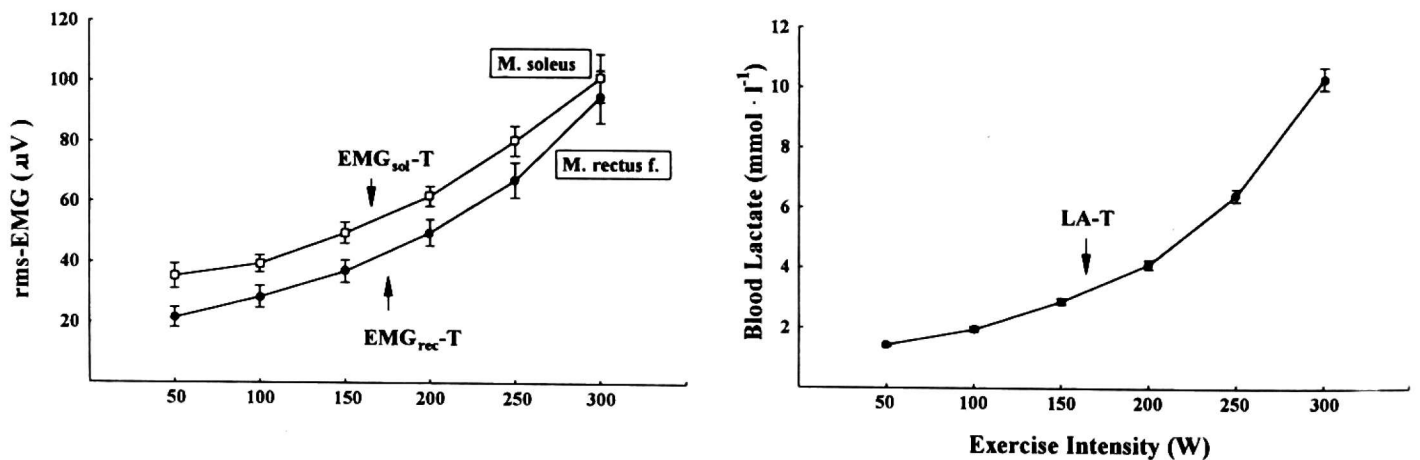


Fig. 1. Average (\pm SE) ms-EMG activity of the rectus femoris and soleus muscles and blood lactate (LA) concentrations during incremental exercise ($n = 28$). The mean threshold exercise intensity detected for EMG in respective muscle group and for blood LA concentrations is indicated here by the arrows as EMG-T and LA-T, respectively.

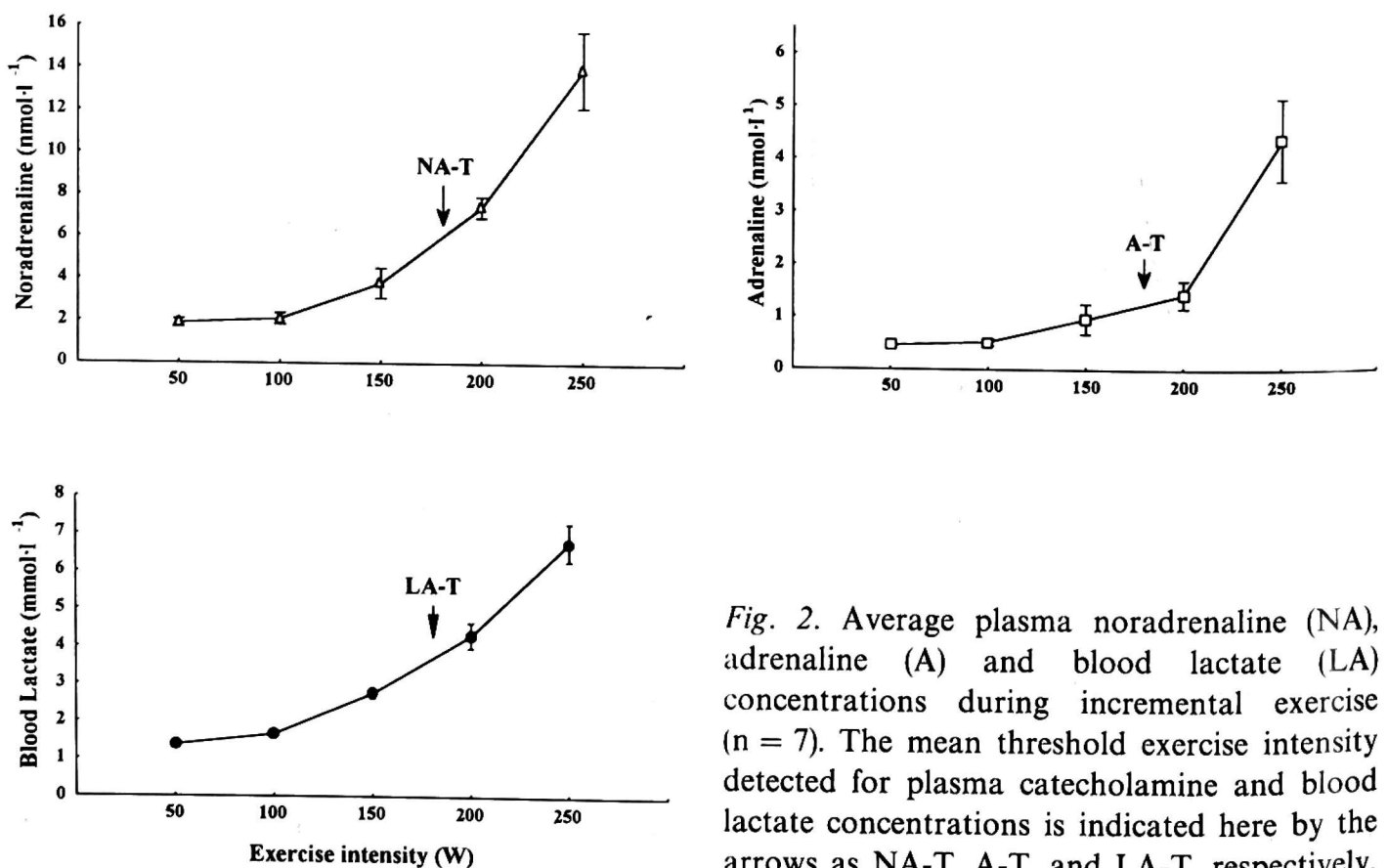


Fig. 2. Average plasma noradrenaline (NA), adrenaline (A) and blood lactate (LA) concentrations during incremental exercise ($n = 7$). The mean threshold exercise intensity detected for plasma catecholamine and blood lactate concentrations is indicated here by the arrows as NA-T, A-T, and LA-T, respectively.

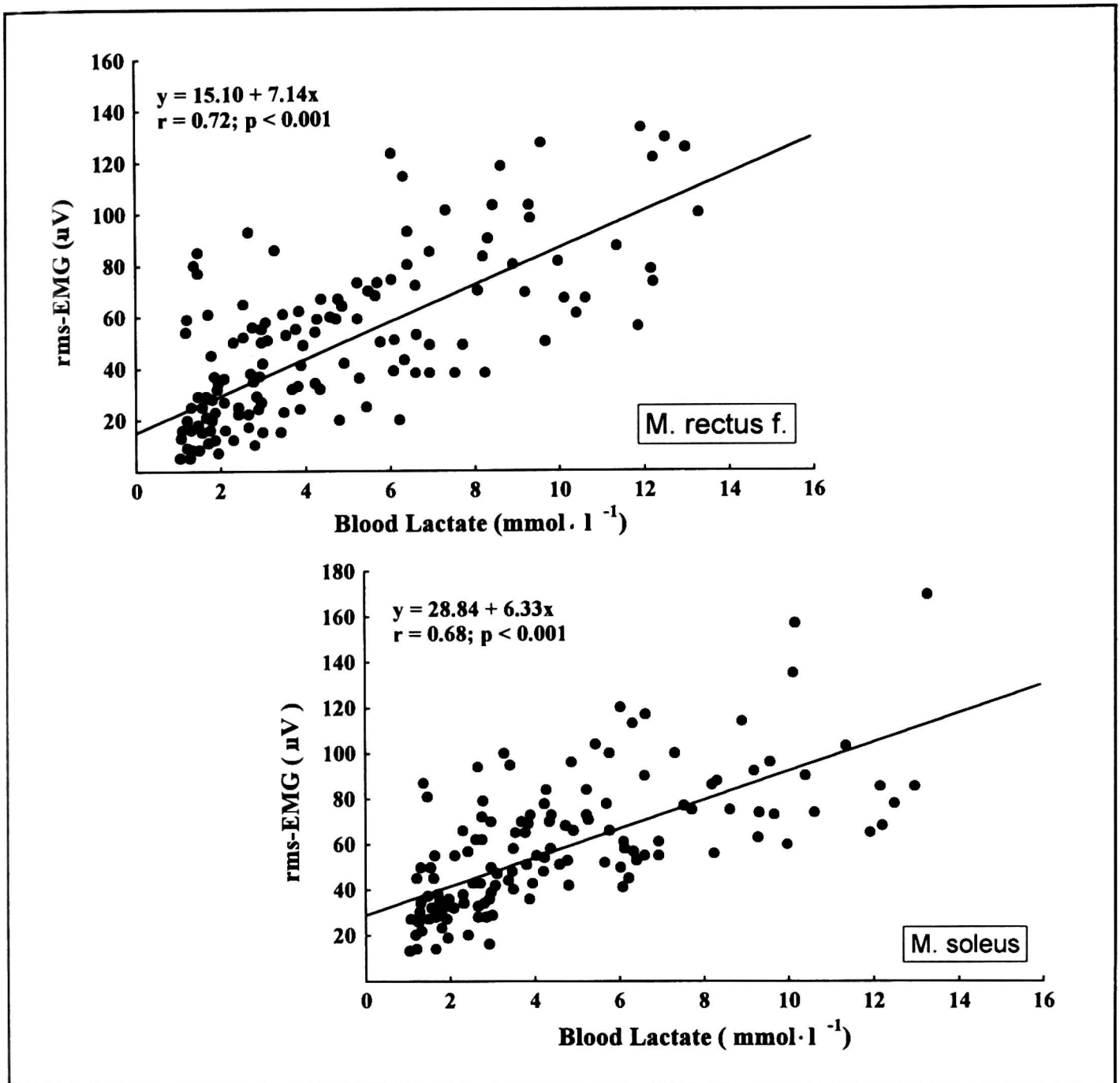


Fig. 3. The relationship between blood lactate concentration and rms-EMG activity of the rectus femoris ($n = 16$) and soleus ($n = 162$) muscles during progressive exercise.

low and moderate intensities. Then, the sudden, nonproportional rise in EMG occurred at the intensities corresponding to the LA-T. Using the log-log plot, the mean threshold WL was detected for the rms-EMG for both of the examined muscles. The mean threshold work load for EMG activity (EMG-T) of the rectus femoris and soleus were 176.3 ± 8.7 W and 171.8 ± 8.9 W, respectively, and for LA-T 164.0 ± 6.9 W. No significant differences were found between absolute and relative threshold VO_2 , HR and WL at LA-T and EMG-T for rectus f. and soleus muscles (Fig. 4). The A-T and Na-T threshold work loads, measured in a group of 7 subjects, were 179.8 ± 5.2 W and 178.0 ± 5.5 W, respectively, and they also did not differ significantly from the LA-T (179.7 ± 6.2 W) (Fig. 2). No significant correlations were found between the threshold values measured in this study.

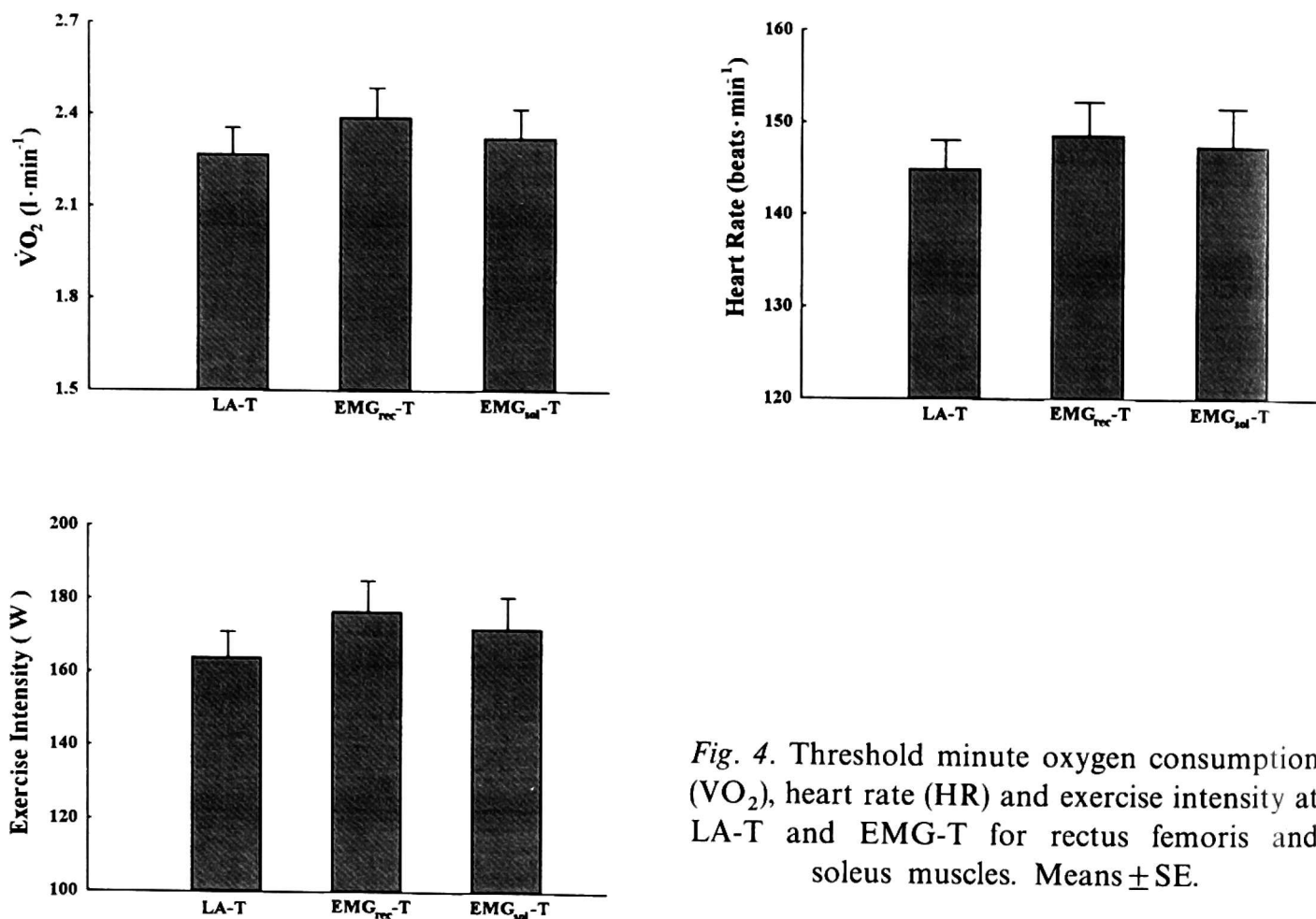


Fig. 4. Threshold minute oxygen consumption ($\dot{V}O_2$), heart rate (HR) and exercise intensity at LA-T and EMG-T for rectus femoris and soleus muscles. Means \pm SE.

DISCUSSION

The results of the present study demonstrated a progressive rise in electromyographic activity of different muscle groups during incremental exercise, confirming the known phenomenon of increasing EMG with development of fatigue. The rise in rms-EMG with increasing exercise intensity revealed an exponential pattern, similar to that in blood lactate and plasma catecholamine concentrations. The similarity of the time-courses of changes in EMG to that of LA during incremental exercise is emphasized by close correlations between the rms-EMG determined from rectus femoris, as well as soleus muscles, and the blood lactate concentrations. These data are in agreement with the previously reported by Chwalbińska-Moneta *et al.* (18) showing a direct relationship between blood lactate and EMG activity in leg muscles fully engaged in dynamic bicycling, and also in nonworking muscle.

During the test performed in the present study both the individual EMG activity and catecholamine concentrations altered negligibly up to the exercise intensities approaching LA-T, and then increased abruptly. This apparent trend for nonlinearity between the EMG activity and exercise intensity is in agreement with previous findings (11, 18, 19). The composition of the muscle (20) does not seem to influence the pattern of the EMG changes during incremental exercise, since no significant differences were found in the present

study between the EMG-T determined for soleus muscle (rich in slow-twitch fibers) and the EMG-T for the rectus f. muscle (mainly composed of fast-twitch fibers). The calculated thresholds of EMG and plasma catecholamine occurred at almost the same exercise intensity as LA-T both when expressed in absolute and relative work load values. The apparent coincidence of lactate and catecholamine thresholds does confirm earlier data (1, 3, 5). From the comparison of the sequence in time of the lactate, catecholamine and EMG thresholds it appears that the LA-T is only tending to occur earlier, i.e. at the lower exercise intensities, than the others. The individual analysis of all the thresholds determined in the study indicated that the LA-T does not always precede the EMG-T or catecholamine-thresholds, as it was also suggested previously (18). However, Taylor and Bronks (21) have reported that lactate threshold had already occurred before the EMG breakpoint during incremental treadmill running. Thus, the equation of the causal relationships between the thresholds remains difficult to answer.

Anyway, the close relationship found in the present study between blood lactate concentration and rms-EMG activity of different muscles during progressive exercise supports the suggestion that local factors such as lactate accumulation in the muscle and the associated metabolic changes play a dominant role in acceleration of muscle fatigue, and subsequent increase in the EMG of working muscles (22, 23). The threshold lactate accumulation in the muscles, preceding the blood lactate threshold, reported by Ivy *et al.* (24) and Chwalińska-Moneta *et al.* (25) may be the reason for EMG-T appearance. However, such a conclusive statement about the mechanism evoking the threshold increase in EMG activity during exercise is still not possible. Since a generalized response of skeletal muscles to physical work, including those which are not directly engaged in exercise, has been shown in our previous study (18) it might indicate a prominent contribution of the central component in muscle motor unit recruitment, for example the dispersed activation of brain cortex motoneurons during physical exercise. In turn, the stimulating effect of the efferent impulses derived from the cortical motor centres also on the control systems of catecholamine release during exercise cannot be excluded, since the important role of central command for the sympathetic nervous system response to various types of exercise has been demonstrated (26).

Furthermore, it can be speculated that there exists a fatigue-feedback mechanism via the central nervous system from and to the working muscles (27). The neural afferent signals from muscle metabolic receptors might participate not only in the stimulation of the EMG activity during exercise but also in the activation of catecholamine release (28, 29).

In conclusion, the present study demonstrated an exponential pattern of increase in EMG activity during progressive exercise, parallel to that in blood lactate and plasma catecholamine concentrations. The EMG threshold

corresponded closely to the rapid, nonlinear increases in blood lactate and plasma catecholamine changes of the threshold character.

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