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THE INFLUENCE OF AMBIENT TEMPERATURE ON POWER AT ANAEROBIC THRESHOLD DETERMINED BASED ON BLOOD LACTATE CONCENTRATION AND MYOELECTRIC SIGNALS

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Abstract
Objectives: To compare the mechanical power and physiological parameters in males at the lactate (LA_{AT}) and integrated electromyographic ($IEMG_{AT}$) anaerobic thresholds during exercise testing at 23°C, 31°C and 37°C. **Materials and Methods:** Fifteen men aged 21.9 ± 1.80 years performed an incremental exercise test on a cycle ergometer at pedal frequency of 60 rpm. The test began at the power output of 120 W which was increased by 30 W every 3 min. Heart rate, oxygen uptake, carbon dioxide in expired air and minute ventilation were monitored. Venous blood samples were collected at 30 s before termination of each 3-min stage of test to determine the lactate anaerobic threshold. $IEMG_{AT}$ for vastus lateralis (VL) and rectus femoris (RF) muscles were regarded as the inflection point at which a non-linear increase in $IEMG_{AT}$ occurred. **Results:** $IEMG_{AT}$ for VL and RF were similar for all the three temperatures. $IEMG_{AT}$ (VL and RF) correlated closely with LA_{AT} at ambient temperatures of 23°C (r = 0.91), 31°C (r = 0.96) and 37°C (r = 0.97). Repeated measures analysis of variance (ANOVA) revealed that the mechanical power at LA_{AT} and $IEMG_{AT}$ was higher at 23°C (202±26.5 W vs. 205±22.9 W) than at 31°C (186±20.2 W vs. 186.2±20.2 W) and 37°C (175.5±25.2 W vs. 175.3±20.0 W) for LA_{AT} and $IEMG_{AT}$ respectively ($p < 0.01$). **Conclusions:** Higher ambient temperature induced a decrease in the mechanical power at which the anaerobic threshold occurred. The high correlation between LA_{AT} and $IEMG_{AT}$ (r = 0.91–0.97) indicated that $IEMG_{AT}$ can be used as a practical and reliable, non-invasive method for assessment of the anaerobic threshold.

Key words:
Ambient temperature, Anaerobic threshold, Lactate threshold, Electromyographic threshold

INTRODUCTION

The environment, particularly air temperature and humidity, has a significant influence on human physiological responses to physical activity. Performing exercise at high temperatures affects blood circulation, which may have a negative influence on the endurance performance [anaerobic threshold (AT) and maximal workload (MWL)]. When an increase in skin blood flow diverts blood away from the inspiratory muscles, we may expect to observe a greater degree of inspiratory muscle fatigue after incremental exercise in the heat compared to exercise at lower temperatures [1]. Endurance exercise capacity is impaired when exercise is performed in hot (30°C) conditions [2]. The increase in heat production and storage during prolonged exercise in a hot environment results in the development of hyperthermia, which

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is thought to contribute to the development of fatigue [3]. Physical exercise at higher ambient temperatures increases the metabolic rate. It was observed that under such conditions the anaerobic threshold was achieved at an earlier point in the exercise time [4], which resulted in a decrease in the maximal workload (MWL) [5]. The anaerobic threshold (AT) occurs at a metabolic rate that is specific to a given individual and is usually caused by an inadequate oxygen supply [6]. This effect has been subject to extensive research [5,7]; however, the underlying mechanisms remain unclear. The data regarding the influence of high [8] and low [9] ambient temperatures on the mechanical power at the anaerobic threshold are inadequate. Little is known about the mechanical power at anaerobic threshold in the heat (31°C and 37°C) and a thermo-neutral (23°C) environment when AT is assessed either with blood lactate (LA) concentration or integrated myoelectric signals (IEMG). The lactate threshold is the exercise intensity that is associated with a substantial increase in blood lactate during the incremental exercise test. Various parameters are used to measure this increase [10–12]. The integrated electromyographic anaerobic threshold is regarded as the inflection point at which an abrupt non-linear increase in the integrated electromyogram occurs, representing the changes in the motor unit (MU) recruitment and/or MU firing frequency during incremental exercise [13]. The relationship between the LA and IEMG thresholds has only been investigated in an exercise tests in the thermoneutral conditions [14–16]. It would be interesting to find whether $IEMG_{AT}$ would bring as accurate results as LA_{AT} in the hot environment. The knowledge about the influence of ambient temperature on the anaerobic threshold might be useful for optimizing the training of professional sportsmen, especially before the contests in different climatic zones.

AIMS AND OBJECTIVES

The study was designed to investigate a correlation between the changes in the electrical activity of working muscles (rectus femoris — RF and vastus lateralis — VL) during the incremental exercise test and blood lactate accumulation at three different ambient temperatures. The main aim was to compare the mechanical power and physiological parameters of males at the lactate (LA_{AT}) and integrated electromyographic ($IEMG_{AT}$) anaerobic thresholds at ambient temperatures of 23°C, 31°C and 37°C.

MATERIALS AND METHODS

Subjects

Fifteen males, mean age 21.9±1.80 years, participated in the study. Their body parameters (mean ±SD) were as follows: body height (BH) — 178.5±4.00 cm; body mass (BM) — 70.5±6.10 kg; percentage body fat (PF) — 13.0±7.90%; body surface area (BSA) — 1.86±0.12 m^2; BSA/BM — 260±17.00 cm^2×kg^{-1}, VO_{2max} — 56.10±5.50 ml×kg^{-1}×min^{-1}.

Study protocol and design

The study protocol was approved by the Regional Biomedical Ethics Committee. BM was measured with Sartorius F150S-DZA (Germany). PF was evaluated using the Slaughter's et al. formula [17]. The subjects attended three trials at ambient temperatures of 23°C, 31°C and 37°C at 1–2 weeks intervals. They performed the incremental exercise test on a cycle ergometer (ER 900

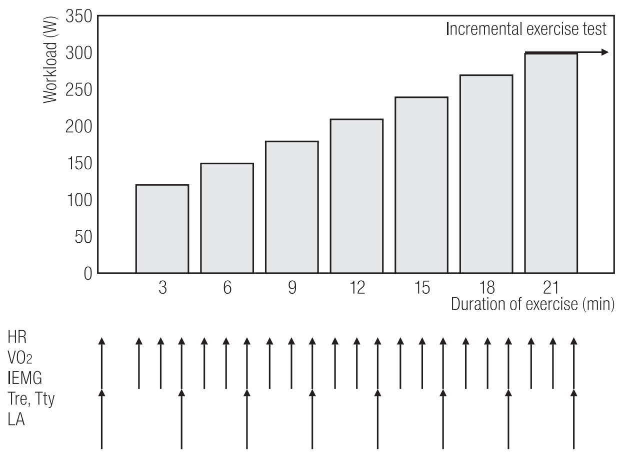

Fig. 1. Diagram of the study parameters for ambient temperatures of 23°C, 31°C and 37°C (The arrows indicate the moment of blood sampling (LA), and the monitoring of HR, VO_2, IEMG, Tre, Tty).

Jeager, Germany) at pedal frequency of 60 rpm. The test began at a power output (PO) of 120 W which was increased by 30 W every 3 min. The study parameters measured during the incremental exercise test are displayed in Figure 1.

During the trial, HR was monitored using S610i™, Polar, Finland. Respiratory gas exchange was analyzed online (M202E, Medikro, Finland). Rectal (Tre) and thympanic (Tty) temperatures were measured with electrothermometer (ELLAB CTF 9004, Denmark). Venous blood samples for lactate determination were taken via a catheter from an antecubital vein after each stage of test lasting 2 min 45 s, and lactate concentration was measured with a miniphotometer (Plus LP 20, DR LANGE, Germany). Lactate anaerobic threshold (LA_{AT}) was determined for each individual using Hughson's method [10].

EMG

The electromyographic threshold ($IEMG_{AT}$) for vastus lateralis (VT) and rectus femoris (RF) muscles was assumed to be the inflection point at which a non-linear increase in IEMG occurred [7,14]. The myoelectrical activity IEMG (µV) was assessed using the Muscle-Tester ME3000P (Mega Electronics LTD, Finland), which rectified and integrated 15–500 Hz. The signals were recorded using surface electrodes (Ag/AgCl, type E50, PW MENOS ZTM, Poland).

Statistics

Statistica 7.0 for Windows package was used for all statistical calculations. A two-way ANOVA with repeated measures was used for data comparison. When the two-way ANOVA revealed a significant interaction, the main effects analysis was used to assess the differences. When the analysis indicated a significant difference, a Newman- Keuls post hoc test was used. The level of probability to reject the null hypothesis was set at $p < 0.05$. All the comparative data are expressed as means ±SD. Pearson product moment correlation coefficient was computed to assess the relationship between the mechanical power at the anaerobic threshold determined based on the blood lactate or myoelectric thresholds.

RESULTS

The electromyographic thresholds ($IEMG_{AT}$) for VL and RF were similar at 23°C, 31°C and 37°C. High correlations were noted between workload at $IEMG_{AT}$ (VL and RF) and

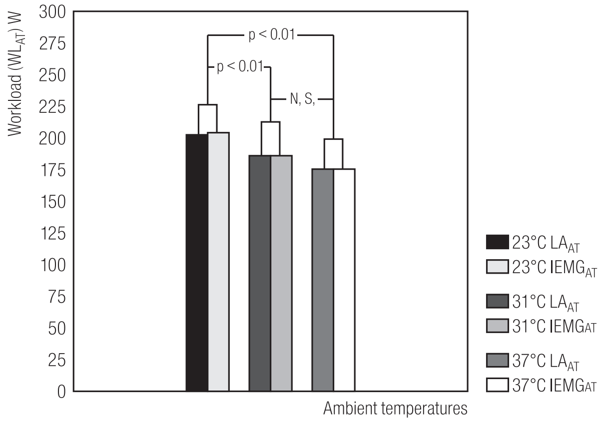

Fig. 2. Workload (WL) level at the lactate (LA_{AT}) and electromyographic ($IEMG_{AT}$) thresholds at ambient temperatures of 23°C, 31°C and 37°C.

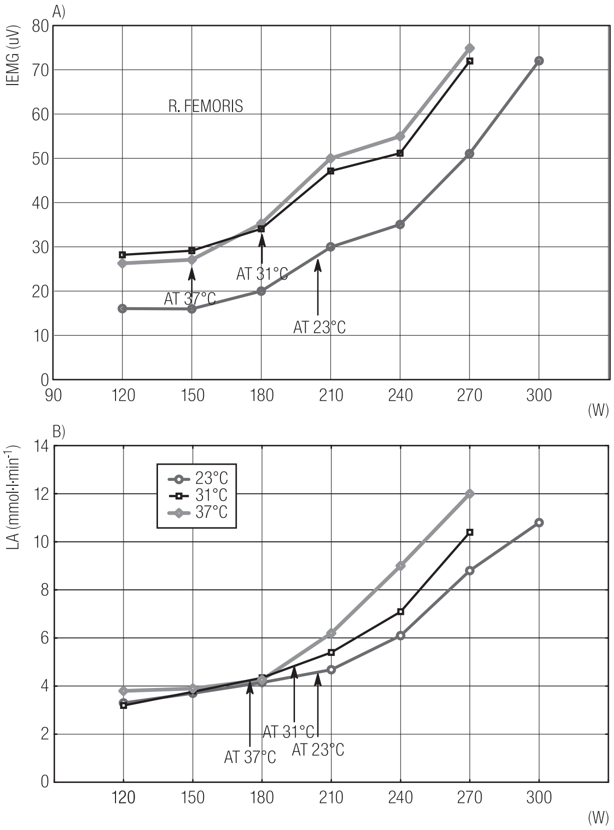

Fig. 3. Average IEMG (µV) activity of rectus femoris (A), and blood lactate (LA) concentration (B) during incremental exercise at ambient temperatures of 23°C, 31°C and 37°C. The arrows indicate the anaerobic threshold for IEMG threshold and blood lactate concentration.

Table 1. The mean value of maximal oxygen uptake (VO_{2max}), maximal heart rate (HR_{max}), oxygen uptake (VO_{2AT}), heart rate (HR_{AT}), blood lactate concentration (LA_{AT}), and rectal temperature (Tre_{AT}) at anaerobic threshold at three ambient temperatures

Parameters	Ambient temperature		
	23°C $\bar{x}$±SD	31°C $\bar{x}$±SD	37°C $\bar{x}$±SD
VO_{2max} (ml×kg^{-1}×min^{-1})	56.0±5.47	55.6±3.82	57.4±3.43
HRmax (b×min^{-1})	191±6.80	192±8.67	193±9.33
VO_{2AT} (ml×kg^{-1}×min^{-1})	42.0±3.11	39.3±3.20	38.8±4.01
HR_{AT} (b×min^{-1})	170±11.61	169±5.98	163±10.11
LA_{AT} (mmol×l^{-1})	4.68±0.94	4.35±1.08	4.26±0.85
Tre_{AT} (°C)	38.0±0.31*	37.7±0.29	37.6±0.28*

* Significant difference ($p < 0.05$).

at LA_{AT} at temperatures of 23°C ($r = 0.91$), 31°C ($r = 0.96$) and 37°C ($r = 0.97$). A significantly higher mechanical power ($p < 0.01$) was found at 23ºC (202±26.5 W vs. 205±22.9 W) than at 31°C (186±20.2 W vs. 186.2±20.2 W) and 37°C (175.5±25.2 W vs. 175.3±20.0 W) for LA_{AT} and $IEMG_{AT,}$ respectively (Fig. 2).

The assessed $IEMG_{AT}$ and LA_{AT} occurred at almost the same intensity of exercise (Figs. 2 and 3).

No statistically significant differences could be found between the maximal oxygen uptake (VO_{2max}), maximal heart rate (HRmax), oxygen uptake at anaerobic threshold (VO_{2AT}) and blood lactate concentration at the lactate threshold (LA_{AT}) in the course of the incremental exercise test at 23°C, 31°C and 37°C (Tab. 1). Statistical differences between rectal temperatures at anaerobic thresholds (Tre_{AT}) were noted only in the tests performed at 23°C and 37°C ($p < 0.05$). Tre reached the highest level (38.0±0.31°C) during the testing at 23°C.

DISCUSSION

Several powerful physiological mechanisms of heat loss are activated during physical exercise to prevent a rise in the rectal temperature (Tre). However, the warm and hot environment can significantly add to the challenge that the physical exercise imposes on the human thermoregulatory system, as the heat exchange between the body and the environment is substantially impaired under these conditions. This can lead to serious performance decrements [18] as well as contribute to decreasing the level of anaerobic threshold during incremental exercise [4]. Dehydration and core temperature are increased during exercise in hot environment. The increased heat load, altered cardiac output, blood redistribution and increased catecholamine release have the potential to alter muscle metabolism. This would imply that the highest rectal temperature should occur at 37°C. However, evidence from our recent studies demonstrates that rectal temperature at anaerobic threshold (Tre_{AT}) reached the highest level at 23°C due to the highest level of workload (WL_{AT}) which coincided with a high release of endogenous heat [5]. Exercising in a hot environment contributes to a higher degradation of muscle glycogen and greater blood lactate accumulation [5]. However, Savard et al. [19] and Yang et al. [20] have shown that during exercise in hot environment, muscle blood flow and muscle glycogen do not decrease more than under the thermo-neutral conditions. There are many reasons for trying to quantify the intensity of exercise; these including the necessity to assess the cardiovascular and pulmonary functions during workload or to evaluate the training programs for sportsmen and categorize the exercise as mild, moderate, or intense. A number of tests have been developed to determine the intensity of exercise associated with the anaerobic threshold. They cover the testing of the maximal lactate steady state, lactate minimum, lactate threshold, onset of blood lactate accumulation, individual anaerobic threshold, ventilatory threshold and electromyographic threshold [5,7,11,21].

The influence of high and low ambient temperature on endurance performance in physical exercise was the subject of interest among researchers exploring the issue of thermoregulation [4,5,9,22–28]. However, few studies concerned the influence of higher ambient temperature on the anaerobic threshold. Flore at al. [28] showed that a decreased workload (WL) at the lactate threshold (LA_{AT}) and an increased blood lactate concentration (LA) occurred at a high ambient temperature (30°C) while opposite findings were noted at low temperature (10°C). These results are consistent with the data reported by Tyka et al. [5]. Most of the research was conducted at three different temperatures: room temperature (20–23°C), and a several degrees higher (about 30°C) or quite high (above 35°C) temperatures. As reported by Kubica et al. [23], the rectal temperature rose very quickly during the first 30 to 40 minutes of physical exercise at room temperature and was followed by a shorter or longer period of stabilization. The same exercise performed at higher ambient temperatures brought about a faster stabilization of rectal temperature. The rate of increase in rectal temperature (Tre) was also higher, which increased the metabolic rate and decreased the level of anaerobic threshold [5]. The increase in rectal temperature also led to a decrease in the maximal workload (MWL) [25] while the maximal oxygen uptake (VO_{2max}) was relatively stable. The present study revealed that during incremental exercise, the workload at the anaerobic threshold (WL_{AT}) was significantly lower at a relatively high ambient temperature. The anaerobic thresholds determined based on the lactate (LA_{AT}) or myoelectric thresholds ($IEMG_{AT}$) at ambient temperature of 23°C, 31°C or 37°C were comparable. It is presumed that during exercise at higher ambient temperatures (31°C and 37°C), the fast-twitch motor units were recruited earlier than at room temperature. Previous research showed that the increased blood lactate accumulation may be related to an increased fast-twitch motor unit recruitment in combination with a decreased blood lactate removal [16,29]. Interestingly, the results obtained using $IEMG_{AT}$, a non-invasive method of anaerobic threshold assessment, in the incremental exercise tests at different ambient temperatures (23°C, 31°C, 37°C) are as accurate as those yielded by LA_{AT} determination, an invasive method.

CONCLUSIONS

Higher ambient temperature induced a decrease in the mechanical power at which the anaerobic threshold occurred. The study demonstrated an exponential pattern of increase in IEMG activity during incremental exercise test, similar to that in blood lactate concentration (LA). The high LA_{AT}-$IEMG_{AT}$ correlation (r = 0.91–0.97) indicated that $IEMG_{AT}$ can be a practical and reliable non-invasive method for anaerobic threshold assessment.

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