

## Effects of Ambient Temperature on Physiological Responses to Incremental Exercise Test

by

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*Physiological variables are regularly analyzed by coaches and sport scientists during an incremental exercise test (IET) until exhaustion. Physiological and biochemical responses of the body are modified upon exercising in the heat as well as results obtained in the IET. Heat changes the validity of these results to be used when prescribing or monitoring training processes and predicting performance in athletes*

*To determine the effect of ambient temperature on physiological responses, twelve physically active men completed IET on the cycle ergometer in three ambient temperatures: 23°C (T23), 31°C (T31) and 37°C (T37).*

*We measured continuously: rectal temperature ( $T_{re}$ ) and aural canal temperature ( $T_{ac}$ ), heart rate (HR),  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , respiratory rate (RR), tidal volume (TV), and minute ventilation ( $V_E$ ). Blood samples for  $LA_{pi}^-$  were taken before, at the end of each exercise step and 3 minutes after the test ended.*

*The exercise duration (DE) and energy expenditure (EE) to reach the threshold of decompensated metabolic acidosis (TDMA) decreased ( $p < 0.05$ ) in T31 ( $11.27 \pm 3.03$  minutes;  $86.2 \pm 24.2$  kJ) and T37 ( $10.72 \pm 2.76$  minutes;  $79.5 \pm 21.3$  kJ) in comparison to T23 ( $13.10 \pm 2.30$  minutes;  $108.8 \pm 23.9$  kJ), with no differences observed in  $LA_{pi}^-$ ,  $V_E$ ,  $\dot{V}O_2$  or  $T_{re}$ . We observed an increase ( $p < 0.05$ ) in  $LA_{pi}^-$  after tests in T31 ( $11.08 \pm 1.89$  mmol/L) and T37 ( $11.94 \pm 2.25$  mmol/L) in comparison to T23 ( $10.26 \pm 2.30$  mmol/L), with no differences observed in  $\dot{V}O_{2\max}$ , end  $T_{re}$ , EE and DE to exhaustion.*

*The TDMA occurs faster and at a lower WL, while performing IET in 31°C and 37°C. Coaches sport scientists should consider these factors when conducting IET to assess the threshold level and performance of athletes..*

**Key words:** hyperthermia, incremental exercise test, TDMA, lactate, performance.

### Introduction

The climate conditions modify the reactions of human body during exercise and affect its performance (Gleeson et al., 2001; Tyka et al., 2007). Intense and long lasting aerobic exercise in warm and humid environment causes heat storage in the body and leads to increase in core temperature. Intense muscles work during that activity causes the increase of

endogenous heat production, because most of energy produced in the muscles is transformed in heat. To avoid heat storage and maintain core temperature on a constant level, excess heat produced by working muscles must be eliminated by intensified thermoregulatory mechanisms. The efficiency of that mechanism depends on the ambient temperature and its humidity (Saat et al., 2005). Heat production and elimination could be maintained at room temperature. But the situation becomes complicated

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when the ambient temperature raises and exceeds the skin temperature. Then convection and radiation of the heat is impossible and the only way the heat can be eliminated is sweat production and its evaporation. Exercise induces body temperature elevation and affects exercise ability, and decreases performance (Kubica, 1979). Knowledge about this favors to optimize training process and performance or to minimize athletes' heat stress.

Athletes are regularly tested by trainers and sport scientists. The incremental exercise test (IET) is one of the ways to verify athletes' efficiency. Results of the IET and physiological parameters measured during the test are modified depending on the many factors like initial work load, increments of work load or duration of each stage (Bentley et al., 2007). Differences in test results may also be due to changes in environmental conditions such as an ambient temperature.

The purpose of our study was to examine physiological parameters and performance measured in incremental exercise test performed in three different ambient temperatures: 23°C, 31°C and 37°C. We hypothesized that higher ambient temperature decreases endurance performance and changes some physiological parameters such as maximal oxygen uptake, maximal ventilation, core temperature or peak plasma lactate. Additionally, we assumed that the threshold of decompensated metabolic acidosis (TDMA) occurs at a lower work load when participants performed the test in higher temperature.

## Methods

### Subjects

We chose 12 healthy, physically active (3 times per week, 1-1.5 hour exercise training, subjectively rated as from moderate to intense), non heat-acclimated males.

Physical characteristics are presented in Table 1. Before participating, all volunteers read and signed an informed consent approved by the regional ethic committee. The same Committee approved the study. Participants were also examined by sports physician.

### Experimental protocol

We conducted all tests in the spring time (mean day temperature was 18-22°C), approximately during a period of 6 weeks. We instructed Participants

to avoid any physical activity 3 days before every visit to the laboratory. For each trial, they arrived at the laboratory at the same time (9:00 AM) to minimize circadian variation in performance and body temperature. Participants were instructed to drink a 500ml of isotonic drink (Gatorade LTD) after a wakeup in the day of the test to avoid hypohydration and more than 1500ml a day before. We used crossover design to minimize heat acclimation. Every session was also separated by a two-week break to eliminate any training effects. Body mass was measured by electronic balance (Type F1505-DZA; Sartorius Company, Germany) with an accuracy of 1g. Calculation of the percentage of body fat was based on the Slaughter (1988) formula. Thickness of skinfolds was measured on the bottom of scapula corner and at the back of the arm. Participants came 3 times to our laboratory to perform incremental exercise test. All tests were performed in a climatic chamber. Every time they performed the test in a different ambient temperature: 23°C (T23); 31°C (T31); 37°C (T37) with 55 ± 5% relative humidity. They entered to the climatic chamber 30 minutes before each test. The test was performed on a cycle ergometer (model ER 900; Jaeger GmbH & Co, Wuerzburg, Germany). The testing protocols were the same in all 3 temperatures.

The exercise began with 3 minutes of warm-up at a work load of 90W. After that, we increased the power by 30W every 3 minutes. Pedaling rate was 60 rotations per minute imposed by a metronome. The exercise was terminated due to voluntary exhaustion or inability to maintain pedalling rate for 5 second. After the test, the subjects cycled with no resistance and at a low pedalling rate for 3 minutes to recover.

We measured expiratory gas continuously during the incremental exercise test using ergospirometry system (model M202E; Medikro Oy, Kuopio, Finland). We monitored gas exchange variables such as ventilation ( $V_E$ ), respiratory rate (RR), tidal vol-

**Table 1**

<i>Participants' Characteristics</i>	
	<i>X ± SD</i>
Age, years	22.6 ± 2.20
Height, cm	175.5 ± 4.0
Mass, kg	71.5 ± 5.52
Body Mass Index, kg/m <sup>2</sup>	23.21 ± 3.1
Body Fat, %	12.1 ± 6.8
$\dot{V}O_2$ max, mL/kg per min	57.48 ± 6.67
$\dot{V}O_2$ max, L/min	4.11 ± 0.47

Table 2

Physiological parameters measured at the  $\dot{V}O_2$ max level in different ambient temperatures ( $X \pm SD$ )

	Ambient Temperature		
	23°C	31°C	37°C
Duration of exercise, min	19.14 ± 1.79	18.81 ± 2.43	18.23 ± 3.03
Heart rate, beats/min	191.0 ± 5.78	191.5 ± 7.50	193.4 ± 8.07
Plasma lactate, mmol/L <sup>a</sup>	10.26 ± 2.30	11.08 ± 1.89	11.94 ± 2.25
Respiratory rate, breaths/min <sup>b</sup>	50.1 ± 7.95	51.8 ± 9.11	54.0 ± 8.57
Tidal volume, L/min	2.52 ± 0.29	2.48 ± 0.35	2.45 ± 0.33
Minute ventilation, L/min <sup>b</sup>	126.9 ± 27.79	128.5 ± 19.38	132.4 ± 22.07
$\dot{V}O_2$ max, L/min	4.11 ± 0.47	4.17 ± 0.84	4.27 ± 0.61
$\dot{V}O_2$ max, mL/kg per min	57.48 ± 6.67	58.19 ± 4.99	59.84 ± 8.70
Rectar temperature, °C	38.15 ± 0.35	38.14 ± 0.33	38.04 ± 0.57
Aural canal temperature, °C <sup>a</sup>	37.68 ± 0.55	38.02 ± 0.20	38.14 ± 0.28

Table 3

Physiological parameters measured at the  $\dot{V}O_2$ max level in different ambient temperatures ( $X \pm SD$ )

	Ambient Temperature		
	23°C	31°C	37°C
Duration of exercise, min <sup>a</sup>	13.10 ± 2.30	11.27 ± 3.03	10.72 ± 2.76
Heart rate, beats/min	168.8 ± 7.92	166.9 ± 8.74	165.7 ± 12.64
Plasma lactate, mmol/L	4.39 ± 0.57	4.40 ± 0.74	4.63 ± 0.56
Respiratory rate, breaths/min	32.0 ± 3.63	33.7 ± 5.36	32.4 ± 3.95
Tidal volume, L/min	2.24 ± 0.27	2.11 ± 0.21	2.13 ± 0.25
Minute ventilation, L/min	72.0 ± 12.55	71.2 ± 9.27	68.9 ± 11.09
$\dot{V}O_2$ , L/min	3.05 ± 0.52	2.94 ± 0.57	2.89 ± 0.42
$\dot{V}O_2$ , mL/kg per min	42.64 ± 4.58	41.11 ± 5.15	40.50 ± 4.36
Rectal temperature, °C	37.79 ± 0.27	37.70 ± 0.22	37.61 ± 0.36
Aural canal temperature, °C <sup>b</sup>	37.26 ± 0.53	37.47 ± 0.20	37.58 ± 0.23

ume (TV),  $\dot{V}O_2$ ,  $\dot{V}CO_2$ . Heart rate (HR) was measured beat to beat using telemetry system (model RS300X; Polar Electro, Finland). We measured rectal temperature ( $T_{re}$ ) using rectal thermocouple probe, inserted 10-15 cm along the anal sphincter. The thermocouple probe was sterilized every time before repeated placement. Aural canal temperature ( $T_{ac}$ ) was measured by placed tympanic thermocouple probe in the aural canal and then isolated from external environment. We collected data continuously using medical precision thermometer (model CTF 9004; Ellab, Denmark).

Blood samples (25  $\mu$ L) were taken from the ear lobe before the test, in the last 15 seconds of each stage and 3 minutes after the test ended. Samples for plasma lactate concentration were centrifuged. Obtained blood plasma samples were stored at -30°C for further analysis of lactate. Analysis of lactate concentration ( $[LA]_p$ ) was made in duplicate on spectrophotometer (model LP-20; Dr Lange, Germany) using colorimetric method.

We analyzed the received gas exchange data after every test and determined the threshold of decom-

pensated metabolic acidosis (TDMA). It was determined individually using V-slope method based on nonlinear increase of  $\dot{V}CO_2$  to  $\dot{V}O_2$  (Reinhard et al., 1979).

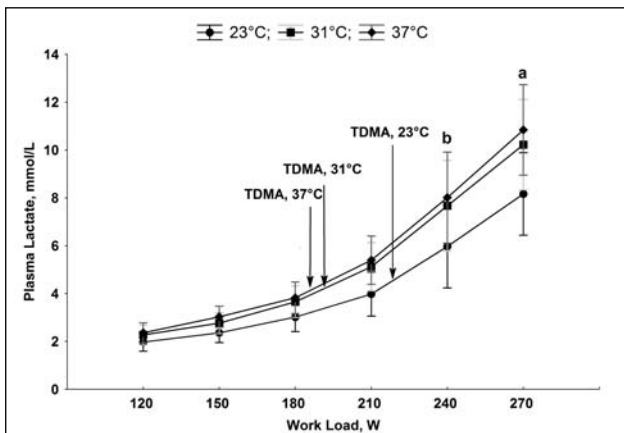
### Statistical analysis

We presented data as mean  $\pm$  standard deviation. We used repeated measures design analyses of variance (ANOVA) to evaluate the effect of thermal factor during incremental exercise tests. We used Tukey Post-hoc comparisons (after obtaining a statistically significant F test from the ANOVA) in order to check which variables are particularly different from each other. The  $\alpha$  - level for statistical significance was set at  $p < 0.05$ . We made all statistical analyses using computer statistical package (Statistica; version 8, Statsoft inc, USA).

## Results

### Plasma lactate and work load

During incremental exercise test we noted that the ambient temperature affected plasma lactate ( $[LA]_p$ )



**Figure 1**

Plasma lactate ( $LA_{pi}^-$ ) at the TDMA level and its changes during incremental exercise tests, performed in different ambient temperatures groups

<sup>a</sup> Significantly higher parameters values observed in ambient temperature 31°C and 37°C in comparison to temperature 23°C ( $p < 0.05$ ). <sup>b</sup> Significantly higher parameters values observed in ambient temperature 37°C in comparison to temperature 23°C ( $p < 0.05$ ).

( $p < 0.05$ ) (Figure 1). We observed higher  $LA_{pi}^-$  at temperature 31°C (T31) and temperature 37°C (T37) in comparison to temperature 23°C (T23). Significantly different  $LA_{pi}^-$  was observed between T23 and T31 starting from work load of 270W, and between T23 and T37 starting from work load of 240W ( $p < 0.05$ )

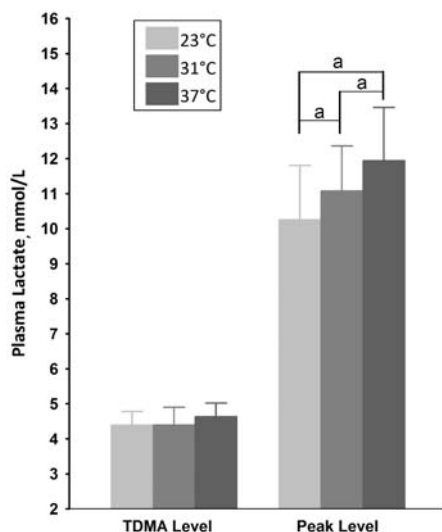
(Figure 1). The peak level of  $LA_{pi}^-$  after progressive exercise was also significantly different ( $p < 0.05$ ) between all 3 temperatures (T23:  $10.26 \pm 2.30$  mmol/L; T31:  $11.08 \pm 1.89$  mmol/L; T37:  $11.94 \pm 2.25$  mmol/L) (Figure 2) with corresponding duration of exercise (Table 2) and energy expenditure (Figure 3). There was no difference between  $LA_{pi}^-$  on the threshold level depending on an ambient temperature, although during incremental exercise test performed in T23 TDMA occurred on significantly higher work load of 210W ( $P < .05$ ) in comparison to T31 and T37 (Figure 1). Earlier appearance of the TDMA in higher ambient temperatures also resulted in significant reduction ( $p < 0.05$ ) in energy expenditure (Figure 3) and duration of time (Table 3) till the threshold appeared.

### Aural canal temperature and rectal temperature

During all incremental exercise tests we observed a gradual increase in  $T_{re}$  and  $T_{ac}$  ( $p < 0.05$ ).  $T_{re}$  at the threshold level and end  $T_{re}$  were similar in all 3 ambient temperatures. Different ambient temperatures during progressive exercise influenced the  $T_{ac}$ . We observed a significantly higher  $T_{ac}$  at the TDMA level and at the end of the test performed in highest temperature, in comparison to T23 ( $p < 0.05$ ) (Table 2, 3).

### Gas exchange parameters

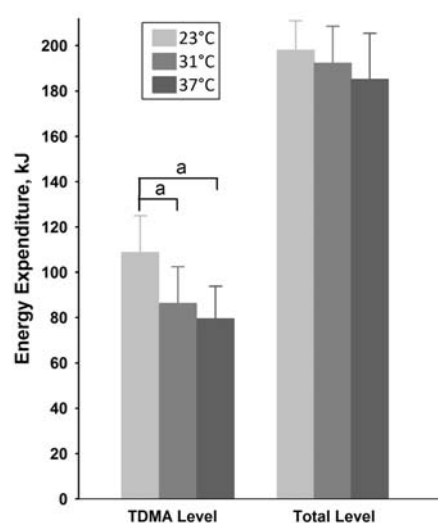
Environmental temperature in which the physical



**Figure 2**

TDMA and peak level of plasma lactate ( $LA_{pi}^-$ ) in incremental exercise test, performed in three different ambient temperatures.

<sup>a</sup> Indicates significant difference ( $p < 0.05$ ).



**Figure 3**

Energy expenditure till the TDMA level and in all incremental exercise test (total level), performed in three different ambient temperatures.

<sup>a</sup> Indicates significant difference ( $p < 0.05$ ).

work was performed affected the changes in breathing parameters. During graded exercise in T31 and T37 we observed significantly higher ( $p < 0.05$ ) minute ventilation ( $V_E$ ) at the  $\dot{V}O_{2, \max}$  level (Table 2). Higher  $V_E$  was due to significant increase in respiratory rate with similar tidal volume (Table 2).

Ambient temperature, in which the participants performed the test, did not affect the oxygen uptake per minute and heart rate both at the TDMA level and peak level (Table 2, 3).

## Discussion

It is well known that intense physical activity entails many changes in human body which lead to maintain homeostasis. The range of these changes depend, among other things, on environmental temperature in which exercise is performed (Wendt et al., 2007). Reports from the past years suggest that high or even elevated ambient temperature decrease the ability to maintain performance during long time exercise, which is associated with dehydration and increase in core temperature (Kubica, 1979; Galloway and Maughan, 1997). It seems that these external and internal factors might have a lesser impact during incremental exercise tests which last about 15-20 minutes. Franc et al. (2001) reported that increase in body temperature is mainly associated with a duration of exercise and its intensity. Casa et al. (2010) concluded that hypohydration contributed as well to the increase in core temperature during exercising, causing an increase of  $0.22^\circ\text{C}$  per every 1% of fluid loss. We did not observe any differences in  $T_{re}$  at the TDMA level and at the end of tests performed in different ambient temperatures. However, we observed a significant increase in  $T_{ac}$  in higher ambient temperatures at the end of tests in comparison to temperature  $23^\circ\text{C}$ . A difference was also observed at the TDMA level in highest temperature. A mechanism of that changes might be explained by differences in tissue blood flow in pelvic and aural canal area (Rowell, 1974). The area of aural canal, which has small mass, is relatively much better supplied with blood than pelvic tissues.

The effect of ambient temperature (Shou and Ishiko, 1994; Tyka et al., 2000), as well as dehydration (Xiao and Toshihiro, 1998; Papadopoulos et al., 2008) on incremental test results and performance, has been investigated in a number of laboratory studies providing different outcomes. From our previous studies, it appears that exogenous heat significantly reduces exercise ability measured as threshold

work load (Tyka et al., 1999; 2000; 2009). We have also observed in this study earlier appearance of the TDMA during incremental exercise test performed in higher ambient temperatures. One of the explanations might be that the TDMA occurred at a lower work load due to stress reaction in response to exogenous heat. Probably greater circulatory and respiratory stress elicits the involvement of sympathetic system and higher catecholamines release (Brenner et al., 1997). It leads to intensified glycogenolysis and glycogen turnover in myofibrils (Powers et al., 1982; Stainsby et al., 1985). Some authors considered that the latter conducts to increase the involvement of anaerobic processes with higher lactate production and releases into blood (Young et al., 1985; Xiao and Toshihiro, 1998; Papadopoulos et al., 2008). It seems that stress reaction influenced by warm environment has some effect on motor units recruitment strategy. In our previous study we observed higher myoelectrical activity (IEMG) on the threshold level during performing IET in hot temperatures. It was also assessed by lower work load on anaerobic threshold (Tyka et al., 1999; 2009). It is presumed that fast motor units are recruited earlier during incremental exercise test performed in higher ambient temperatures than in thermo-neutral temperature. The insufficient oxygen delivery to working muscles might also cause earlier activity of fast motor units. The reason of this could be explained by the reduction of blood flow in working muscles in higher ambient temperatures (Stainsby et al., 1985). During the exercise in warm environment the redistribution of circulating blood is observed (Smolander et al., 1987; Gleeson et al., 2001). Gonzales-Alonso et al. (1999) proved significant decrease in leg blood flow with co-existing increase in muscle glycogen utilize, muscle lactate accumulation and net lactate release after 20 minutes of exercise in  $35^\circ\text{C}$ . Blood flow tended to increase during control trial in neutral temperature. However, participants performed both trials on a steady state level (González-Alonso et al., 1999). We did not find any standpoints in literature describing blood flow in muscles during incremental exercise test.

The redistribution of circulating blood while exercising in hot environment appears to play a particularly important role in changing physiological response and limiting performance. Increase in ambient temperature coexisting with increased skin temperature reduces significantly visceral blood flow. Rowell (1974) observed reduction of visceral

blood flow by 64% in rest during exposure to exogenous heat and Sawka et al. (2001) observed a reduction by 82% in moderate to intense exercise in 30°C. Visceral blood flow is lower during intense physical work (Nielsen et al., 2002), reduced in the same proportion to the increase in heart rate (Rowell et al., 1965). Rowell et al. (1965) noted that while exercising in warm temperatures there is a lower lactate turnover and higher blood lactate concentration due to significant decrease in hepatic blood flow. Probably for this reason we observed higher lactate concentration after incremental exercise test performed in higher temperatures.

We did not observe any differences in maximal oxygen uptake during our study in tests performed in higher temperatures, which was consistent with the result obtained by Schou et al. (1994). However, in another study (Xiao and Toshihiro, 1998), researchers have demonstrated a decline of  $\dot{V}O_2 \text{ max}$  and  $V_E$  with concomitant increase in heart rate and blood lactate in incremental exercise test performed in 40°C. It is worthy underlining that participants begun the test after thermal dehydration in sauna (Xiao and Toshihiro, 1998). That fact might have provoked a more intensified circulatory strain leading to exhaustion before achieving  $\dot{V}O_2 \text{ max}$ . It is known that body hyperthermia up to 38°C and dehydration up to 2.5% of body mass caused by sauna, as well as diuretic dehydration or passive heating by

themselves, limit physical capacity measured in the 105%  $\dot{V}O_2 \text{ max}$  test (Nielsen et al., 1981). Exogenous heat modified some respiratory parameters in our study. The highest peak level of minute ventilation ( $V_{E \text{ max}}$ ) was observed in the test performed in temperature of 37°C mainly due to increased respiratory rate without increase in tidal volume. These changes are similar to those of previous laboratory (Tyka et al., 2009) and indicate that high temperature during incremental exercise test, as well as during prolonged heavy endurance exercise, does not restrict respiration and oxygen intake (Romer et al., 2004).

### Conclusions

We have evaluated the differential effects of ambient temperature on physiological parameters in incremental exercise test. The differences that have been noted in our study are linked mainly with a stress reaction, higher circulatory strain and redistribution of circulating blood in higher temperature. We provided information that may be useful for trainers and scientists working with professional athletes. Thus, we recommend to pay attention to ambient temperature during testing athletes in sports laboratory because it might impair correct estimation of threshold level, training loads or starting strategy during competition.

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### **Acknowledgement**

The study was supported by a research grant from the Academy of Physical Education in Cracow.

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