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Physical performance and body response to physical work in hot environment

Wydolność fizyczna a reakcja organizmu na wysiłek fizyczny w podwyższonej temperaturze otoczenia

INTRODUCTION

It is established that endurance can be impaired in the heat [3, 6]. It is known that during physical exercise heat production varies from about 80 kcal/h at rest to more than 1400 kcal/h during maximal exercise Generated heat have to be removed from the body by radiation, conduction and vaporisation of water in the respiratory passage and on the skin. The balance between heat production and heat loss determines the body temperature. Dynamic prolonged exercise can marked increase in muscle temperature and additionally increased ambient temperature lead to fatigue [3]. Fatigue during prolonged exercise in hot ambient temperature is mainly connected with: increased glycogen depletion, dehydration , alteration in electrolyte distribution across the sarcolemma, changes in cardiovascular response [3].

Our study examined:

- metabolic factors of fatigue occurred during two hours submaximal exercise in ambient temperature of 20^{o} C (NT) and 30^{o} C (HT) in low and high aerobic performance subjects.
- the effect of hot ambient temperature on energetic cost of exercise and contribution of carbohydrate, fat and proteins in catabolic processes in both groups of subjects

MATERIALS AND METHODS

Twelve physical education students (age 21 –2 3 years) volunteered for this study. The subjects were divided in two groups: low physical performance group (LP) and high physical performance group (HP). The base o division were main aerobic components values: VO_2 max in ml O_2 / min/ kg b.m. and values of anaerobic threshold (AT) in % VO_2 max .

Peak oxygen uptake (VO_2 max) and anaerobic threshold (AT were measured for each subject during incremental cycling exercise . Seven days after VO_2 max test, subjects participated in two bouts of exercise . Each bouts required subjects to cycle at 45 % VO_2 max during 120 min. in ambient temperature of 20^o C and 30^o C with relative humidity of about 50 %. Oxygen uptake (VO_2), expiration of CO_2 (VCO_2) heart rate (HR) , pulmonary ventilation (V_E), metabolic equivalent (MET i.e. 1 MET = 3.5 ml of oxygen per kilogram of body weight per minute) were determined continuously during exercise using gas analyser EOS SPRINT Jaeger. During the 120-min lasting exercise, the subjects were allowed water ad libitum. Blood samples were drawn before and during exercise (after first and second hour of exercise) and 15 minutes post exercise, to measure parameters of acid-base equilibrium, haemoglobin, hematocrit and lactic acid (LA) concentrations. Blood lactate concentration was determined enzymatic method using Sigma kit.Urine was collected 24 h before and 24 h after exercise to determine concentration of urinary nitrogen and uric acid , using required Sigma Kits. Total energy expenditure and percentage of energy derived from carbohydrate, fat and protein were estimated using indirect calorimetry and Nutrition programme of Jaeger.

Statistics. All reported values are means ± SD. The data were statistically analysed according to the t-Student's test using the variance analysis. The level of $p< 0.05$ was considered as statistical significant.

RESULTS

The anthropological and physiological parameters of subjects participated in experiments are shown in table 1. Our results are shown in figure 1 –12. Both groups of subjects: LP and HP performed twice two-hours lasting exercise at 40% – 50 % anaerobic threshold (AT) in conditions of ambient temperature 20^o C and 30^o C. Because both groups differed in values of VO_2 max (table 1) thus, they performed cycloergometric physical exercise, which intensity was the same i.e. 35 % - 40 % VO_2 max, but power of exercise was different The both groups differed from rest energy expenditure and from percentage contribution of carbohydrate, fat and protein in yielding of energy. Resting energy expenditure at 20^o C was 3585,1±15,9 kcal/24h and 2611,5±260,27 kcal/24h in LP and HP group, respectively (Fig. 5). In control group the energy was yielded from carbohydrate, fat and protein in the following proportion: 48,6 % ± 2,8% , 40,2% ± 2,3% , 11,2 % ± 1,8% , while in athletes main energetic substrate was carbohydrate , which contributed in 66,3 % ± 13 % (Fig. 6, 7). In HP group 26,9 % ± 8,4 % and 12,8 % ± 4,5 % energy was yielded from fat and protein, respectively (Fig. 7,8). But prolonged, submaximal exercise performed at 20^o C and 30^o C changed profiles of energetic substrates in both groups of subjects. In LP group, carbohydrate become the main source of energy (Fig. 6) , whereas in HP, contribution of fat increased in significant degree (from 26,9 % at rest to 36 % during work at 20^o C) (Fig..7). In these conditions, protein uptake increased about twice at 30^o C in both groups (Fig.8). During 2-h lasting exercise heart rate gradually increased in all subjects (Fig. 1, 2). However, the rise in HR was greater when exercise was performed in the heat and was significantly different ($p< 0.05$) from the neutral environment. Increase of heart rate was more intense in control group (fig.1). During the exercise in neutral environment, MET rose continuously in both groups of subjects (Fig.3, 4). But, exercise in the heat resulted in a larger increase in MET than that in the neutral environment. What more, in the untrained group changes of this parameter were more pronounced (Fig.3).

Prior to exercise blood lactate averaged 1,7 ± 0,2 mM and 1,8 ± 0,1 mM in athletes and control group, respectively (Fig.9, 10). Blood lactate concentration rose during exercise in 20 ^{o}C to 2,8 mM and 2,5 mM in LP and HP group, respectively. The larger increase in blood LA concentration resulted during work in hot (up to 3,0 mM and 3,8 mM in HP and LP group, respectively) (Fig.9). After the work in neutral environment, uric acid excretion did not change. In contrast, during recovery after the heat exercise, we seen in both groups the continuous rise of uric acid concentration in urine (Fig 11, 12).

DISCUSSION

The main aim of this study was to determine whether higher physical performed subjects fatigued during prolonged work in hot environment at the same manner regardless to the metabolic perturbation and cardiovascular response, like the low physical performance one.

The changes observed in heart rate and MET demonstrate that the prolonged exercise performed by subjects in neutral temperature increased physiological and metabolic cost of work in both examined groups, however , the changes in control group were more pronounced. It is mainly due to activation of mechanisms responsible for heat loss, because the production of heat increased dramatically during prolonged exercise [1, 5, 8]. Heat stress appears to affect the distribution of blood flow during submaximal exercise, but causes little or no increase in cardiac output [9]. Exercise in hot environment sets up a competition between the active muscles and the skin for the limited blood supply. During prolonged work, the circulatory system transports oxygen into tissues and the heat generated in the muscle to the surface of the body, where the heat can be transported to the environment. Under this circumstances distribution of blood flow as well cardiac output has to increase . But cardiac output increase only due to the heart rate increase, because stroke volume decreases [2]. The cardiovascular responses due to thermoregulatory processes observed in our study appear similar to responses described by Rowell [9] .

The effect of heat environment on metabolism during muscle exercise has been extensively studied [1, 3, 8], but conflicting information exist with regard to the substrate utilisation during prolonged exercise in hot environment. The effect of heat-exercise stress on the energy expenditure and quantitative participation of substrates to the energetic cost of exercise was investigated in this paper . We observed that in both examined groups, hot ambient temperature slightly increased contribution of carbohydrate in yielding energy during 2-h exercise at a relative intensity 40 % VO_2 max and decreased free faty acid uptake about 42% and 20% in subjects of HP and LP, respectively. In this study we also shown, that the prolonged exercise in hot caused about twice increase of protein uptake in both examined groups of subjects. It is interesting, that training didn't cause any sparing effect on protein uptake in these conditions.

In agreement with another authors [3, 8], we observed that exercise in the heat significantly elevated blood lactate level above that which occurred during exercise under thermoneutral conditions. In trained subjects, increase of blood lactate concentration was milder than untrained one. The elevated blood lactate concentration occurred during prolonged - low intensity exercise in the heat have been suggested to be due to: a reduced blood flow to the active muscle which results in local hypoxia [7], a decreased hepatic lactate clearance (9), the increased levels of catecholamines, which could cause activation of glycogenolysis not only in the active but also in non -active muscle.

Some authors investigated muscle energy balance during exercise by measuring IMP levels in muscle biopsy samples [7]. Muscle IMP accumulation is validated as a marker of energy imbalance within skeletal muscle Due to technical difficulty , we investigated not IMP concentration, but final product of purine degradation, i.e. uric acid excretion to urine after exercise in heat conditions. We have shown that during 3 hours of recovery after prolonged exercise in heat ,urine excretion of uric acid increased about 30 % and about 76% in HP and LP group, respectively. Whereas, concentration of uric acid in urine after work in 20^{o} C was not changed.

In conclusion, the results of the present study suggest that increased ambient temperature may decrease exercise endurance capacity at least in part by deterioration of muscle energy balance, by increase of acidification and uptake of protein and by increase in heart rate and reduction in SV. These changes are the same in both groups of subjects, but they are more pronounced in LP group. Exercise training performed in temperate climate reduces the effects of heat stress during prolonged exercise.

REFERENCES

1. Febraio M.A. et al.: Muscle metabolism during exercise and heat stress in trained men: effect of acclimation. J. Appl. Physiol. 76, 1994 , 589 – 597
2. Fritzsche R.G. et al.: Stroke volume decline during prolonged exercise is influenced by the increase in heart rate .J.Appl.Physiol. 86, 1999, 799-805
3. Galloway S.D.R., Maughan N.R.: Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man.Med. Sci. Sports Exerc. 29, 1997, 1240-9
4. Gonzales-Alonso,J.,Jmora-Rodriguez,R., Below,P.R., Coyle,E.F.: Dehydration markedly impairs cardiovascular function in hypertermic endurance athletes during exercise. J. Appl. Physiol. 82, 1997, 1229-1236
5. Gonzalez- Alonso J. et al.: Heat production in human skeletal muscle at the onset of increase dynamic exercise. J. Physiol. 524, 2000, 603-615
6. Kozłowski S. et al.: Exercise hyperthermia as a factor limiting physical performance temperature effect on muscle metabolism. J. Appl. Physiol. 59, 1985, 766-773
7. Norman B.B.et al.: Increased IMP content in glycogen-depleted muscle fibres during submaximal exercise in man. Acta Physiol.Scand. 133, 1988, 97-100
8. Parkin J.M. et al.: Effect of ambient temperature on human skeletal muscle metabolism during fatiguing submaximal exercise. J. Appl. Physiol. 86, 1999, 902- 908
9. Rowell L.B.: Human Circulation, Regulation During Physical Stress. New York:Oxford University Press, 1986, 363-406.
10. Walterts T.J. et al.: Exercise in the heat is limited by a critical internal temperature. J.Appl.Physiol. 89, 2000, 799-806

STRESZCZENIE

W tej pracy badano wpływ podwyższonej temperatury otoczenia na czynność układu krążenia i metabolizm podczas długotrwałej pracy u ludzi o małej (LP) i dużej wydolności fizycznej (HP). Dwunastu studentów wychowania fizycznego wykonało 2-h pracę fizyczną o intensywności 40 % VO_2 max w temperaturze 20^{o} C i 30^{o} C. U wszystkich badanych stwierdzono ciągły wzrost HR podczas pracy w obu temperaturach, przy czym wzrost był wyższy w temperaturze 30^{o} C o około 23,5 % i 30%, odpowiednio w grupie LP i HP. Cał-

kowity wydatek energii podczas pracy w temperaturze 30° C wzrósł o 40% w grupie LP i obniżył się o 10 % w grupie HP. W obu grupach badanych podczas pracy w podwyższonej temperaturze wzrosło zużycie cukrów i białek, przy czym wzrost był nasilony w grupie LP. Podobnie stężenie LA we krwi wzrosło do wartości 3,5 mmol/l i 4,3 mmol/l odpowiednio w grupie HP i LP. Stwierdzono także zwiększone wydzielanie kwasu moczowego do moczu w grupie LP po pracy w 30° C. Podsumowując można stwierdzić, że zwiększona aktywność fizyczna w temperaturze obojętnej prowadząc do zwiększenia wydolności fizycznej, jednocześnie podnosi tolerancję na stres termiczny.

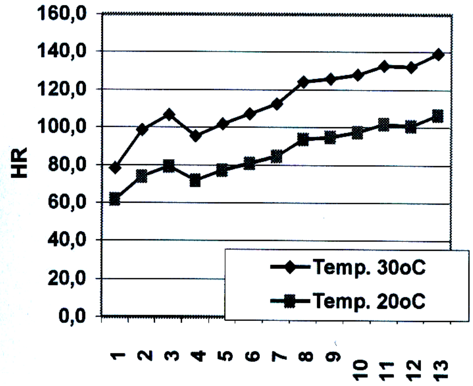
SUMMARY

To examine the effect of ambient temperature on cardiovascular adjustment and metabolism during prolonged exercise , twelve of high and low performance subjects (LP and HP groups) cycled during 2h at a workload requiring 40% peak oxygen uptake on the separate ambient temperature: normal 20° C and hot - 30° C. In both temperature heart rate increased significantly through exercise in all examined subjects ,being 27% and 40% higher at 30° C in LP and HP group, respectively. Simultaneously, the rate of MET increased in the same conditions, being 23,5% and 30% higher in LP and HP subjects, respectively. Total energy expenditure during work at 30° C compared to work at 20° C decreased about 40% in HP and increased about 10% in LP subjects. In both groups of subjects during work at 30° C , the percentage of energy derived from protein and carbohydrate increased, but changes were more pronounced in LP subjects. Despite similar blood LA concentration at rest, after work at 30° C LA concentration raised to 3,5 mmol/l and to 4,3 mmol/l in HP and LP subjects, respectively . There was an exercise-induced increase in uric acid secretion more pronounced at 30° C in LP subjects. In conclusion, we can ascertain that higher physical activity in thermoneutral conditions leading to higher physical performance can improve the physiological response to the heat stress.

Table 1. Anthropometric and physiologic characteristics of subjects

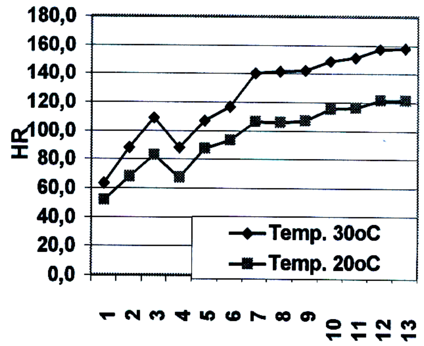
Values are Mean ± SD

Subjects	Age in years	Weight in kg	Height in cm	VO_2 max in l/ min	VO_2 max in ml/min /kg	AT in ml/min /kg	AT in % VO_{2max}
Low physical performance	24 ± 1,4	76,8 ± 5,2	179 ± 3,8	3,73 ± 0,5	49,5 ±3,7	29,3 ± 6,2	58,9 ± 9,4
High physical performance	23,5 ± 1	71,5±3,3	178,8±4,9	4,59±0,1	64,0 ± 2,1	44,5 ± 6,7	65,8 ± 5,3



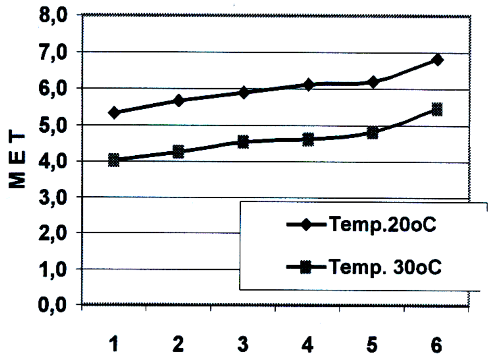
1-rest: 2 - 13 during work at every 10 min

Fig. 1. Heart rates changes in control group during 2-h lasting exercise in temperature 20oC and 30oC



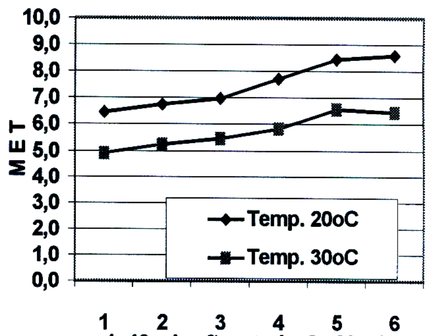
1- rest ; 2-13 during work at every 10 min

Fig.2. Heart rate changes in trained group during 2-h lasting exercise in temperature 20oC and 30oC .



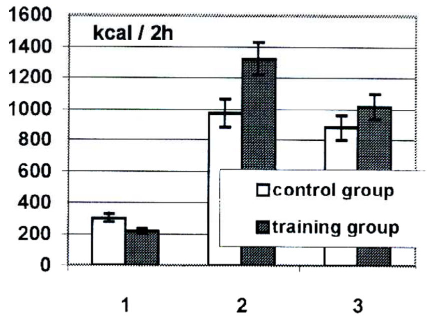
1- 10 min after work, 2- 20 min, 3 - 30 min , 4 -1 h, 5- 1.5 h . 6- 2 h after work

Fig 3. Changes of MET during 2-h lasting exercise in temp. 20o C and 30o C in control group



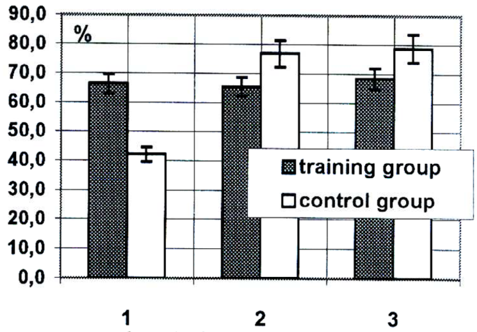
1- 10 min after work, 2- 20 min, 3- 30 min , 4- 1 h , 5- 1,5 h , 6- 2 h after work.

Fig .4. Changes of MET during 2-h lasting exercise in temp. 20o C and 30o C in training group.



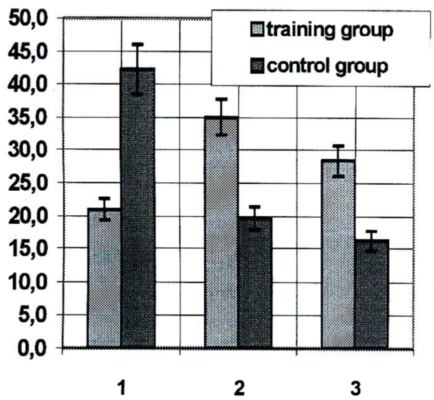
1 - rest, 2 - work, 20oC, 3 - work, 30oC

Fig.5. Total energy expenditure at rest and during 2-h lasting exercise



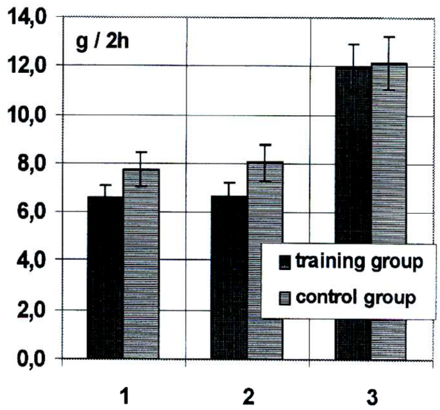
1-rest, 2- 2-h work, 20oC, 3 - 2-h work, 30oC

Fig. 6. Percentage of energy delivered from carbohydrate at rest and during 2-h lasting exercise in 20o C and 30o C



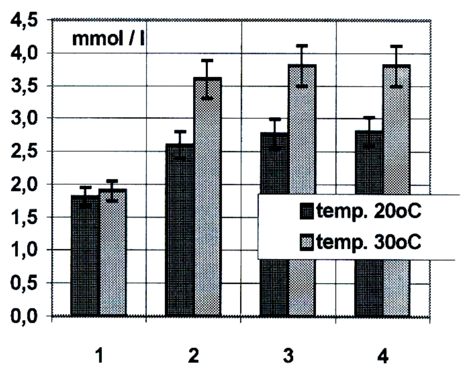
1-rest, 2- 2-h work in temp. 20oC, 3- 2-h work in temp. 30oC

Fig.7. Percentage of energy delivered from fat during 2-h lasting exercise in temp. 20o C and 30o C .



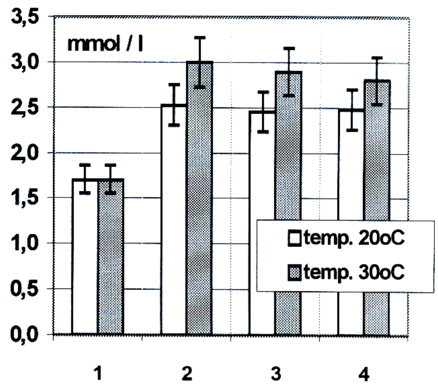
1 - rest, 2 - work, 20oC, 3 - work, 30oC

Fig. 8. Protein contribution in energy yielding during 2-h exercise in temp. 20o C and 30o C



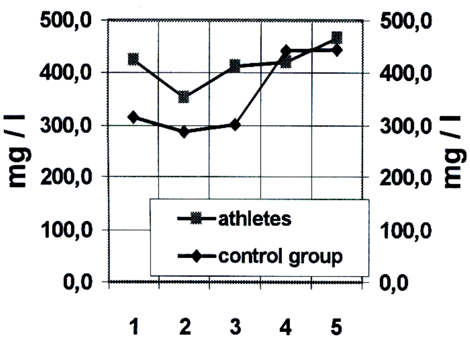
1-rest, 2- after 1th -h work, 3- after 2h work, 4- 15 min after 2-h work

Fig.14. Blood lactic acid concentration after 2-h exercise in control group



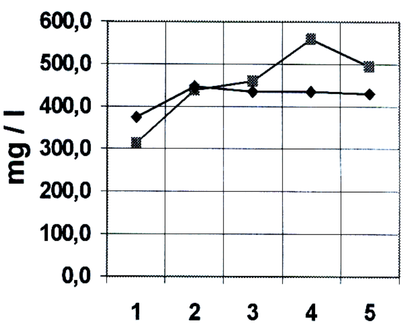
1- rest, 2- after 1th h of work, 3- after2-h work, 4- 15 min after 2-h work

Fig.15. Blood lactic acid concentration at rest and after 2-h exercise in training group.



1- rest, 2- just after work, 3 - 2-h after work, 4 - 3-h after work, 5 - 24 h after work

Fig.11. Uric acid excretion to urine at rest and after 2h work at 20oC.



1-rest, 2- just after work, 3- 2-h after work, 4- 3-h after work, 5 - 24-h after work

Fig. 12. Uric acid excretion to urine at rest and during 2 h exercise at 30oC.