THE EFFECTS OF DIFFERENTIATED AMBIENT TEMPERATURE ON PHYSIOLOGICAL AND BIOCHEMICAL TRAITS DURING REPEATED WINGATE TESTS [1]

by

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The aim of the study was to analyse the indices determining the maximal anaerobic power and related to its physiological and biochemical components during repeatetive Wingate Tests at three ambient temperatures (24°, 32° and 37°) at stable humidity (50%). The investigated group included 14 men at the age of 20–22, students of Univ. School of Physical Education, with different levels of training. Before, during and after efforts (done in thermo-climatic chamber) the following parameters were registered:

Mechanical ones, characterising maximal power (number of rotations, time of developing the maximal power, values of maximal and relative power, the rate of power decrease, the average power).

physiological; temperatures of skin, muscle and rectum, HR, Ht

biochemical: $[H^+]$, $[HCO_3]^-$, $[Na^+]$, $[K^+]$, [Cl-], level of lactates.

As far as it was possible with such a small sample, the statistical characteristics ($\bar{x}$, SD) were calculated. Apart from total group characteristics, the individual variability was estimated for each parameter. Calculations were done for two groups divided according to the maximum power criterion.

It was found, that external temperature had a definite impact on all analysed parameters, especially the mechanical ones and body thermo-regulation. Optimal temperature for reaching the maximal anaerobic power was 32° C. Twenty minutes' rest proved too short for full recovery, but it had no influence on the results of the next test.

Significant and multidirectional inter — individual differentiation resulting from the level of training point out to the fact that while testing humans we should take into account the heterogeneity of examined groups. It means that the same methods should be used in human physiology as in other biological sciences (sample size, representativity, limitation of statistical methods).

Small size of examined group and "averaging" of their results must be treated as certain incorrectness (especially while estimating the scale of the phenomena), and generalisation of results to the whole population is not justified.

Key words: Exercise physiology — Wingate Test — Thermo-regulation

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Introduction

One can find many papers relating to anaerobic efficiency which decides about the abilities to execute short duration efforts of maximum intensities. This efficiency depends both on energy supply to the muscle and on the type of muscle structure (% of fibres ST and FT).

Wingate Test (Bar-Or 1978) is universally used and regarded as the most adequate measure of anaerobic efficiency. It allows to determine several indices of anaerobic efficiency, such as maximum power, average power, relative average power, total anaerobic work, time of development and maintaining the maximum power or time of developing the maximal power.

We can mention here some recent works describing the use of Wingate Test to estimate anaerobic efficiency: Heberstreit et. al. (1996) where the changes of plasma metabolites in boys and men were investigated, Gaul et. al. (1995) where the differences of anaerobic power in boys and men were studied, or the works relating to investigations of muscular metabolites during 30-sec. test in women (Jacobs et. al. 1982).

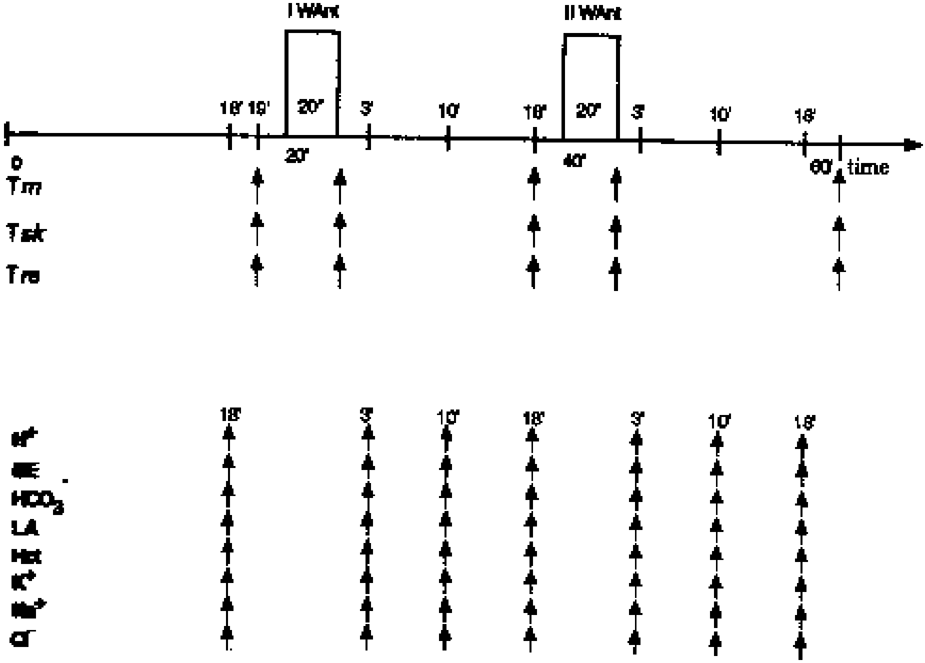
In spite of many reports on methods of measurement of anaerobic efficiency and their conditionings — both genetic (Bouchard et. al. 1988, Simonean et. al. 1986) and (widely understood) environmental (review Inbar et. al. 1996), one can find only few papers (Clark and Royce 1965, Edwards et. al. 1972, Sargeant 1990) whereby MAP should be conditioned by such external factors as increased ambient temperature or the numbers of effort repetitions. Taking into account the difficulties in executing muscles work due to temperature raise, temperature of environment and the role of metabolic processes in repetitive efforts –all these are present in many disciplines of sport -– this problem is very important. Little has been reported on the relations between biochemical changes of blood during maximum effort (Mainwood and Cechetto 1980, Inbar et. al. 1983, Parkhouse and Mc Keenzie 1984, Sharp 1986,Hebestreit et. al. 1996). As the results are still open to discussion, that would merit further research. The present paper is an attempt to clarify certain issues.

The aims of this study were:

1. Determining the impact of different ambient temperatures on anaerobic efficiency examined by repetitive, 20 sec' Wingate — Test
2. Examining how physiological and biochemical parameters of organism are vary during repetitive Wingate Test at different temperatures?
3. How do the individual values of MAP influence the physiological reactions caused by Wingate Test?

Material and methods

The material included the results of tests run for 14 students of Univ. School of Physical Education in Cracow, at the age of 20–22, body mass 68–82 kg and body height 175–190 cm. Every individual test — efforts were executed at three different ambient temperatures: 24, 32 and 37°C. These temperatures are comparable: average room temperature, average weighed skin temperature and internal temperature of organism, respectively. The experiment was run in thermo-climatic chamber at constant air humidity (50%), in accordance to the diagram below:



This scheme was obligatory for every temperatures, the pause between the tests was 3 days in order that ambient temperatures were as required.

The experiment was run in morning — hours, after a light — meal consumed about 1,5 h before the beginning. Those running the tests were the same persons (including physician), also the studies were run under permission of the Ethical Commission of Polish Academy of Science. Tested people spent 60 minutes in thermo-climatic chamber each time, during the 20-th and 40-th minute they performed a 20- second' Wingate Test (Bar-Or 1978). This test was done using the cycloergometer „ Monark", connected to the device SWM-01 measuring the time of each turn with the accuracy of 0,001 seconds. Resistance was adjusted individually, depending on the body mass. This test makes it possible to determine the main components of anaerobic efficiency: maximum anaerobic power (MAP), average power, time of achieving the maximum power, time of its maintenance, total work capacity) or the rate of power decrease. It is necessary to determine the level of MAP — the time of shorter turn — it was calculated by summing up and then averaging the times of quickest rotations in the intervals of three seconds. To calculate the total work and the average power one used the results of resistance of pedalling (kp), time and number of rotations. The time of maintaining the maximum power was calculated summing up times of the rotations from the shorter ones to its decrease, for about 0,02 sec.

During the experiment the following temperatures were registered: rectal (Tre), muscular (Tm) and skin (Ts). Measurements were taken according to the plan, using the Ellab-type thermometer equipped with suitable sensors. Muscular temperature was measured by pricking to the depth of 2,5 cm of the side — head vastus lateralis (Nielsen 1983), rectal temperature by introducing the sensor to the rectum to the *depth of about 15-20 cm (Nielsen et. al. 1983, Kubica et. al. 1989), and skin temperature was taken as the average weighed temperatures; obtained from the formula (Haughty and Du Bois):*

$$Ts = 0,07t_1 + 0,35t_4 + 0,14t_7 + 0,05t_9 + 0,19t_{10} + 0,13t_{13} + 0,32t_{10}$$

Apart from the above parameters, the heart rate was registered with Sport-Tester (TM GBL 165020), at the intervals of 5 sec. Analysing the results one took into account the results of before- effort HR and maximum HR during the first and second effort.

Apart from physiological indices, the biochemical parameters were also investigated. Parameters of acid-alkaline equilibrium were marked in venous blood with the Corning 238device: $[H^+]$, $[HCO_3]^-$ as well as the excess or shortage of buffering alkaline (BE) BA.

Lactates concentration was marked in plasma using the test Bio - - - Merieux. Also Ht — the number was registered using the centrifugal separator (error indications out to the maximum of 0,5) . It is much more precise method than commonly used Dill — Costill method (modified by Harrison et. al. — 1982), where the measurement error was about 2g %.

The studies were supplemented with plasma concentrations of selected ions, such as: Na^+, K^+ and Cl^- using Corning 480 device. Na^+ concentration was given with the accuracy of 0,1 mmol/l, K^+ 0,01 mmol/l and Cl^- 1 mg. /l.

The result were then analysed statistically.

Statistical analysis, when applied to a small numbers of individuals, involves certain limitations as the sample is not representative; there are considerable deviations from normal distribution, examined groups are not homogenous (individual values are very important) etc. In physiological research using animals this problem is solved by using inbred rather than homogenous populations. In physiology of man this is impossible, examined groups are heterozygotic; it causes large variability of physiological reactions. This involves certain limitations; the most important being the following:

1. Conclusions can be drawn relating to examined groups only, without possibilities of their generalisations to the population — the test of significance differences is not justified here (Oktaba 1974).

2. It is necessary to interpret the results mainly in descriptive categories as estimations of tendency of changes, not the ins scale.

3. It is necessary to verify the measures of central tendency basing on individual data (the repeatability of the phenomenon is most important) and the scatter values.

Taking into account these limitations, the following methods were used:

1. Arithmetic means and standard deviations SD were calculated for each parameter.

2. Because of distinct differentiation inside the group both in magnitudes and in scale of changes of each parameters resulting probably from degree of individuals trainability, we decided to divide the examined persons into groups according to maximum anaerobic power criterion: group 1- to 800 W, group 2- above 800 W.

For groups 1 and 2 the arithmetic means and SD were calculated, while differences between them were expressed as Z — values.

$$Z=\frac{2\,(\bar{x}_1-\bar{x}_2)}{SD_1-SD_2}$$

These values make it possible to make intertraits comparison and specific typology, which enabled the verification of hypothesis defining the relationship between training effects and magnitude of physiological reactions.

Results

1. Mechanical parameters.

Basic statistical characteristics are documented in Żychowska's (1997) work — in the present study the graphic illustration is presented only.

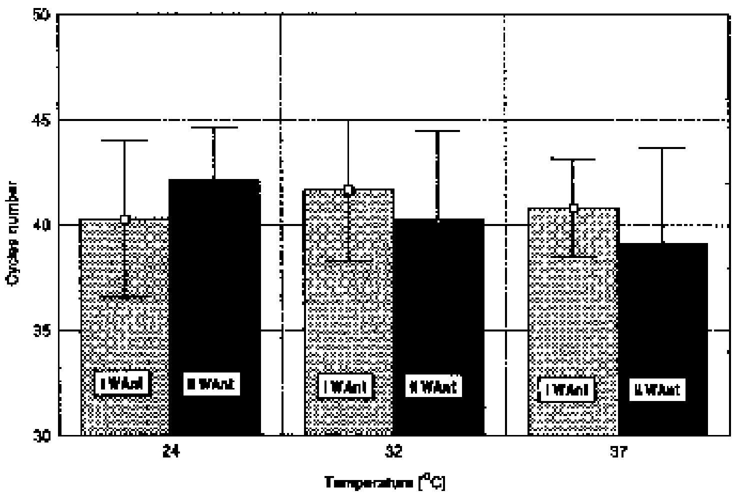


Fig. 1. Cycles number in repeated Wingate — Test at three ambient temperatures

Average number of cycles (Fig. 1) was greatest during the second effort at the temperature of 24°C. Only at this temperature, the examined persons achieved better results during the second rather than the first effort. At the temperature 37°C the *average number of rotations was considerably lower during the second tests.* It is interesting that during first tests the best results were achieved at 32°C, but during the second effort a distinct regularity appeared whereby the average number of rotations was lowered with increasing ambient temperatures. Simultaneously, SD increased — it points out to greater intragroup differentiation resulting probably from different degree of individual adaptation to repeated efforts of maximum intensities (during the first tests just the reverse tendency could be observed).

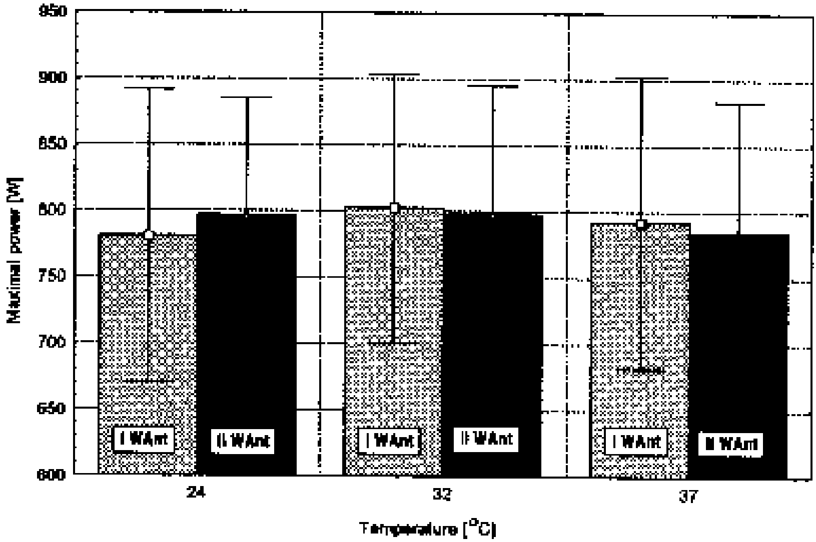


Fig. 2. Maximal power in repeated Wingate — Tests at three ambient temperatures

The values of average maximal power (Fig. 2) displayed a certain variability.

At the temperature 24°C the examined persons developed greater power during the second effort, while at other temperatures --- during the first one. Greatest mean values of maximum power were registered at the temperature 32°C, where the difference between the first effort and second was the least marked. Intragroup variability in this case was nearly the same as at other three temperatures and — what is interesting — a little greater during the first than the second effort.

Similar regularities, though on a larger scale, were found for mean values of maximum relative power (Fig. 3). At the temperature of 24°C the mean results are clearly higher (about 0. 3 SD) during the second effort, while at remaining temperatures — just the opposite. The greatest average values were recorded at the temperature 32°C, however the temperature displayed significant individual variability. That requires a deeper analysis. We have to remember that the distinct gradient is observed during the second effort: it is greater at the temperature 24°C, growing smaller at other temperatures.

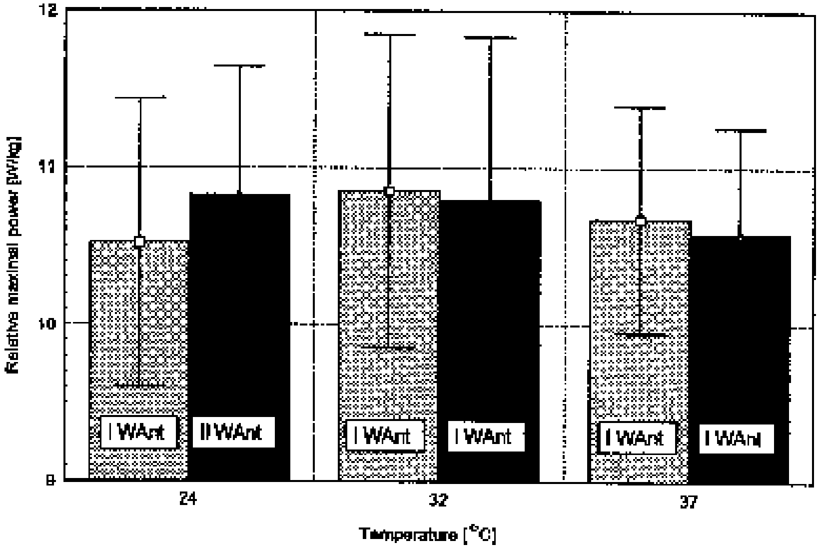


Fig. 3. Relative maximal power in repeated Wingate Tests at three ambient temperatures

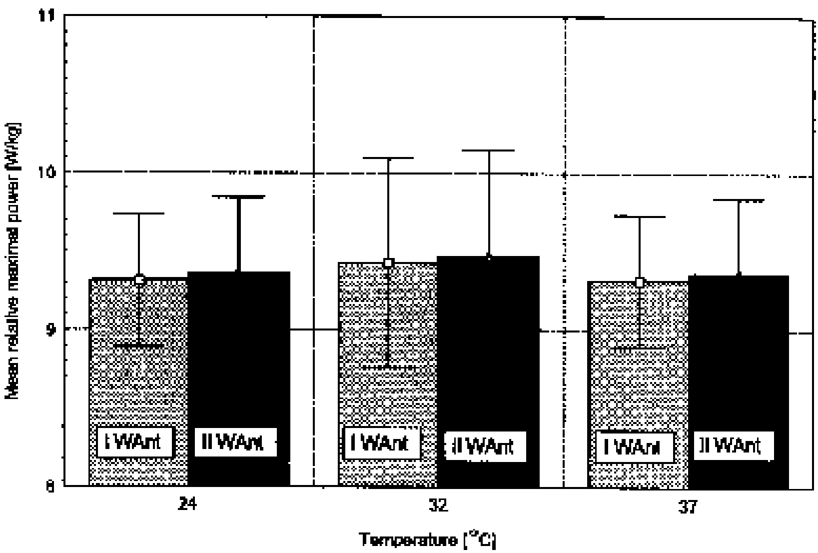


Fig. 4. Mean relative power in repeated Wingate — Tests at three ambient temperatures

Relative average power (Fig. 4) gave a different pattern from that of maximum power. First of all, the results of the second effort are slightly higher for all ambient temperatures. Secondly, intergroup variations are less significant, especially at the temperature 24 and 37°C. Furthermore, the scale of these differences is considerably smaller than in the case of average maximum power: it seems that the general magnitude of power developed by examined persons (the capacity of anaerobic sources) is less sensitive to environmental conditions than maximum power.

Apart from energetic factors, it is very interesting to analyse the variability of remaining basic parameters characterising the efficiency of the whole anaerobic mechanisms: co-ordination component — speed of muscles mobilisation, and resistance to tiredness (Szopa et. al. 1999).

The first of them determines the time of developing the maximum power (Fig. 5.).

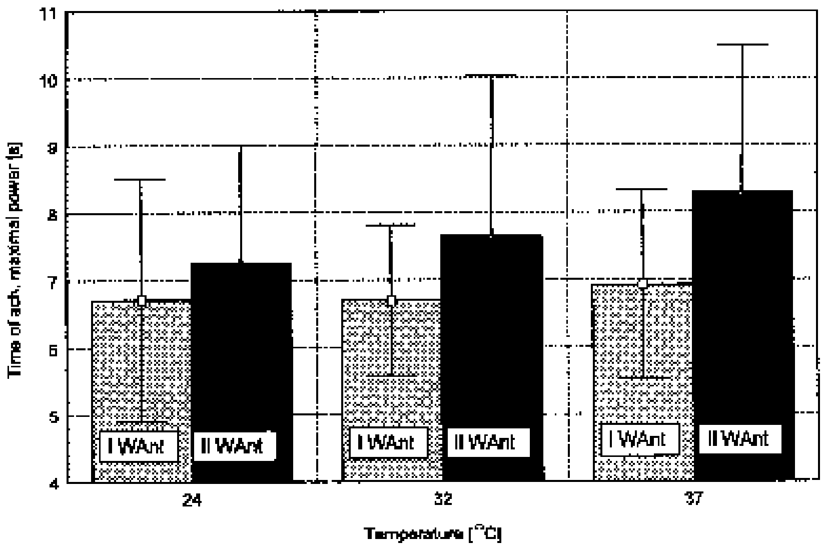


Fig. 5. Time of development of maximal power in repeated Wingate Tests at three ambient temperatures

The values during the first efforts were similar at all temperatures, individual variability was growing (SD circa. 2,2 sec). During the second efforts a distinct tendency appeared whereby the time of developing the maximal power lengthened considerably (circa 1 SD); also more significant intergroup variations could be observed, which produced considerable individual variations (at 32°C SD — carried for about 2,5 seconds — over 30% of the mean values).

Muscles resistance to tiredness was characterised by two parameters: time of maintaining the maximum power (Fig. 6) and the mean values of relative power decrease (Fig. 7)

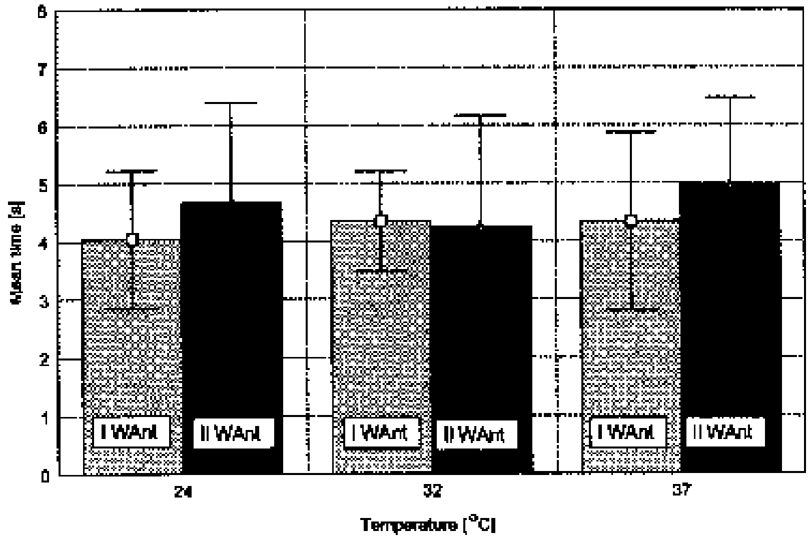


Fig. 6. Mean time of maintenance of maximal power in repeated Wingate — Tests at three ambient temperatures

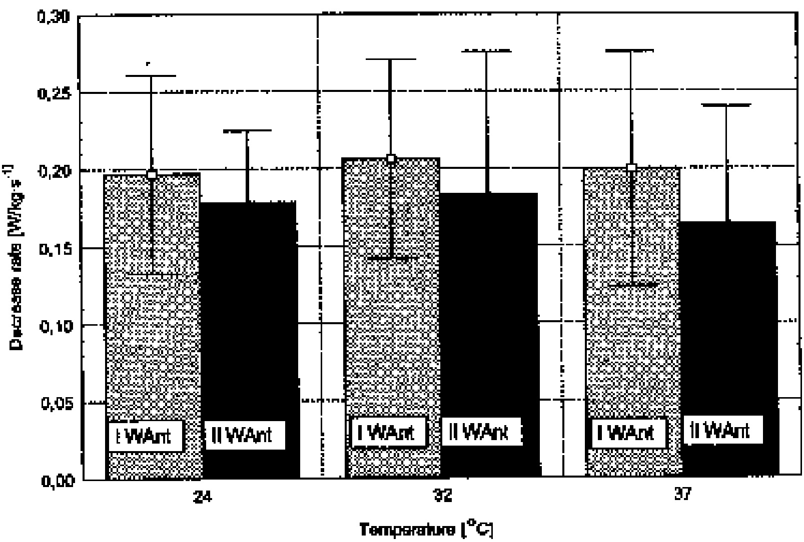


Fig. 7. Decrease rate of maximal power in repeated Wingate — Tests at three ambient temperatures

During the first efforts the temperature did not significantly impact any parameters (a little longer at the temperature 32°C and 37°C); just the reverse tendency could be observed during the second efforts (lower values at 32°C and increasing at the temperature 37°C). The mean time of maintaining the maximum power is a little longer at the temperature 24 and 37°C. Its dependence on temperature is most stable at 32°C; the individual variations are t least significant, especially during the first efforts. At the temperature 32°C the relative power decrease is slower (Fig. 7); at the same time the intragroup variability is most significant.

This parameter is very similar during the first effort, while in the case of the second efforts it is definitely least marked at the temperature 37°C. Basing on the data presented above, we can easily explain the comparatively little differentiation of relative and average maximum power (Fig. 3 and 4). It is proved that it is a result of interference of different tendency of changes of components parameters. High level of power can produce a long time of attaining the maximum power, and also a long time of its maintenance and slower rate of decrease (at 37°C, second effort). This confirms the earlier suggestions about the existence of individual differences, apart from the degree of trainability.

The mean values of maximal HR (Fig. 8) were as expected. The differences between the first and the second efforts at three temperatures were not very large (0,2–0,3 SD), but showed a marked tendency. Every time the mean HR was higher during the second effort. It is worth noting, that the values of HR did not attain their maximum values during the efforts of this type, at least in majority of examined persons (variability ranged from 143 to 204 Hr min^{-1}). This problem will be analysed in further sections.

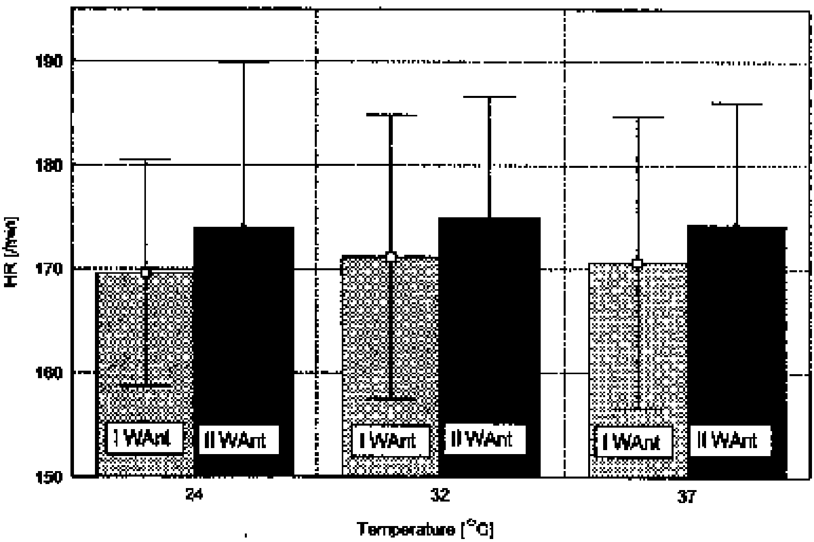


Fig. 8. Effort HR in repeated Wingate — Tests at three ambient temperatures

The changes of body temperature (skin, rectal and muscular) are interesting, as they depend both on the sequence of efforts and ambient temperatures. They are shown as a graphs (Fig. 9, 10, and 11), because these parameters displayed continuous variability.

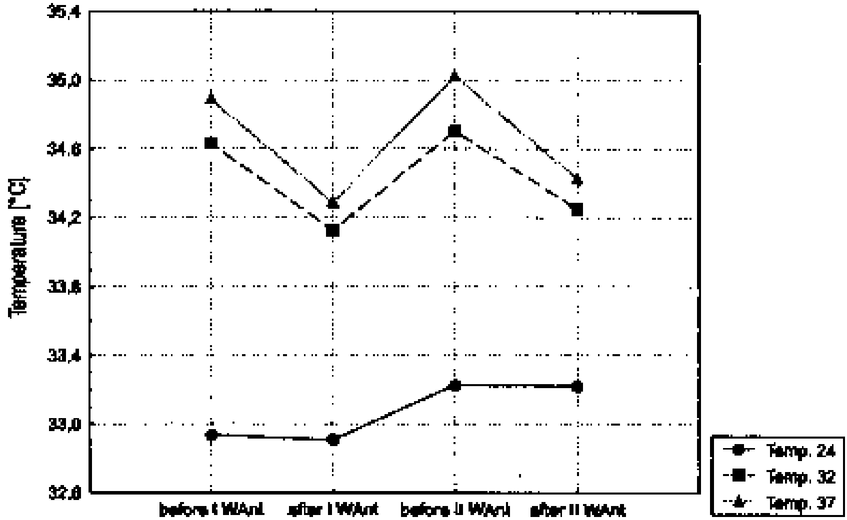


Fig. 9. Skin temperatures during the experiment

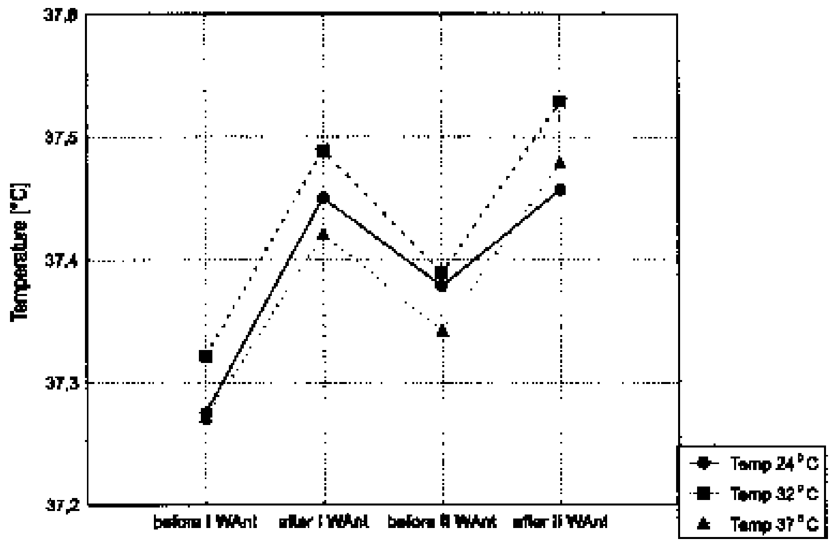


Fig. 10. Muscular temperatures during the experiment

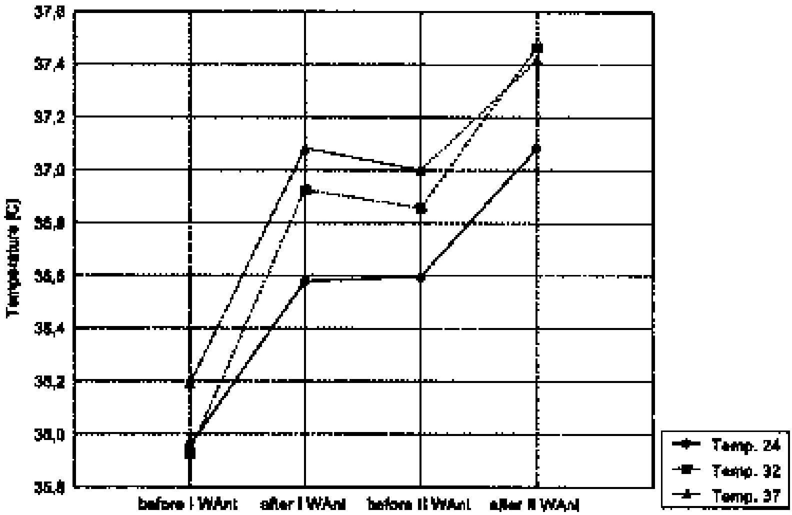


Fig. 11. Rectal temperatures during the experiment

Skin temperature (apart from the efforts at 24°C) clearly lowered after both efforts, but rectal and muscular temperatures inversely — clearly increased after efforts. Skin temperatures decreased after muscular work at the temperature of 32° C and 37°C; it is due to perspiring. The increase of muscular temperatures after the efforts is greater (0,4–0,8°C) than rectal temperatures (the mean increase was about 0,15–0,2°C) and its dependence on external temperatures is least marked (the difference is just 0,05°C only). The pattern may thus seem inconsistent. The scale of changes of skin and muscular temperature is dependent on the ambient temperatures: it is smaller at 24°C and greatest at 37°C. It clearly indicates that heat is removed from the skin in the processes of thermo-control.

One should also pay attention to the scale of variability of each parameter. In all examined external temperatures the greatest individual differences were noted at the skin temperature. SD values were respectively: 0,51–0,65 for temperatures 24°C, 0,40–0,52 for temperatures 32°C and 0,68–1,26 for temperatures 37°C. Variability of muscular temperature is less significant, and the least was for rectal ones, where it would not exceed 1°C.

Analysis of biochemical parameters

The changes of [H^+] at three different temperatures are presented in Fig. 12. The variability pattern is as expected.

In the third minute after the first effort the average [H^+] attained the highest values, afterwards it systematically decreased until the moment of blood intake before the second effort. This concentration did not return to the initial levels. It was

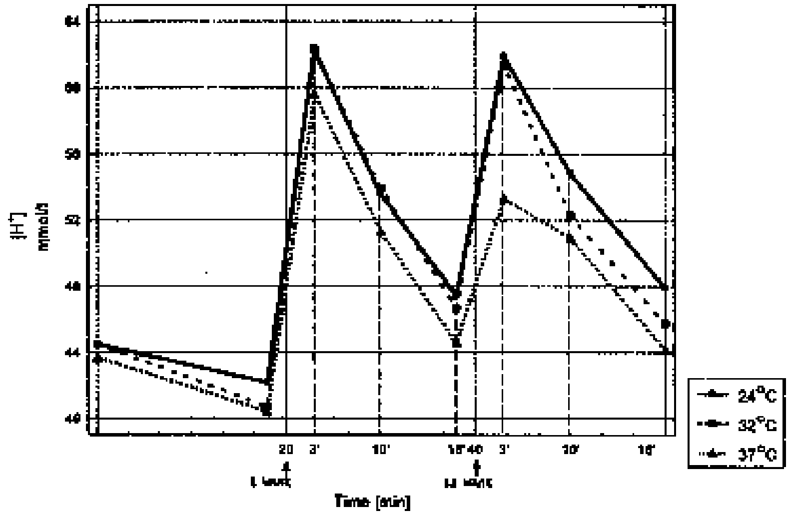


Fig. 12. Concentration of H^{+} ions during the experiment

ascertained that the twenty minutes' rest between intensive efforts is too short to full compensation. It is interesting, however, that after the second effort $[H^{+}]$ did not increase more than after the first one. At the temperature of 24°C and 32°C the patterns of changes and the levels of this parameter similar. At the temperature of 37°C the average $[H^{+}]$ after the second effort was distinctly smaller than after the

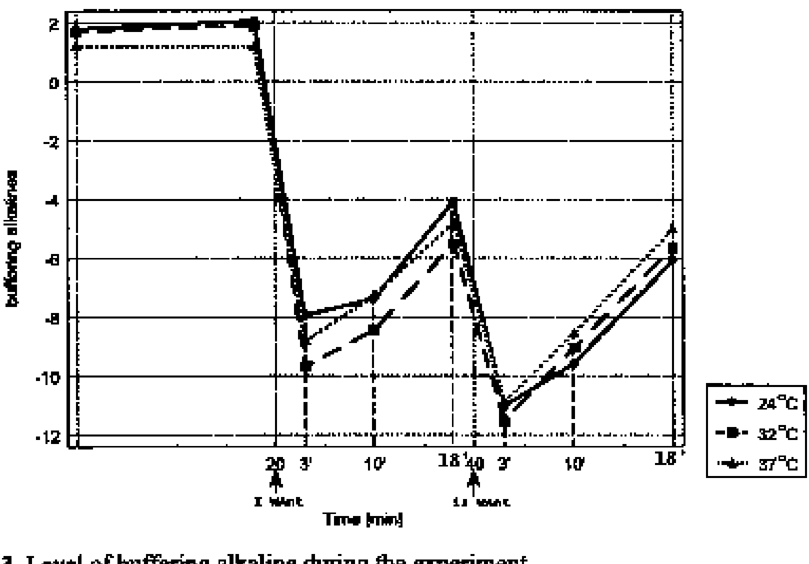


Fig. 13. Level of buffering alkaline during the experiment

first. It seems that the temperature 24 and 32°C did not differentiate between the examined persons with respect to this parameter. Lower level of [H+] noted at the temperature 37°C indicates the possibility of attaining high values of power at lower acidifying.

The highest individual [H+], [giving 103.8 mmol/l in the sample of blood received after the second effort at the temperature 32°C]. The minimum level being 49 mmol/l, thus value of standard deviation was very large. This problem will be discussed in detail in the next section, where we shall analyse the results with regard to intergroup differentiation. Similar to [H+], the mean values of buffering alkaline (Be) (Fig. 13) differed too. The greatest reduction of alkaline levels could be found in samples of blood taken in the third minute after efforts.

The rate of BE decrease was however similar at all three ambient temperatures, which does not explain the previously mentioned changes of [H+]. The least content of alkaline (that is to say the most considerable decrease) was observed at the temperature 32°C after both efforts. Disregarding the ambient temperature, the buffering alkaline were reduced greatly in samples obtained after the second effort. Comparing Fig. 12 and 13 one can note an obvious regularity, that the higher [H+], the greater the shortage of buffering alkaline. It can be also seen that the rate of neutralisation [H+] is faster than that of alkaline concentration decrease. Twenty minutes' pause between efforts proves too short to compensate for after-effort changes, in relation to it every next effort deepens these changes. It is worth noting, that at diminishing [H+] concentration , the level of BE increased (with the exception of temperature 37°C).

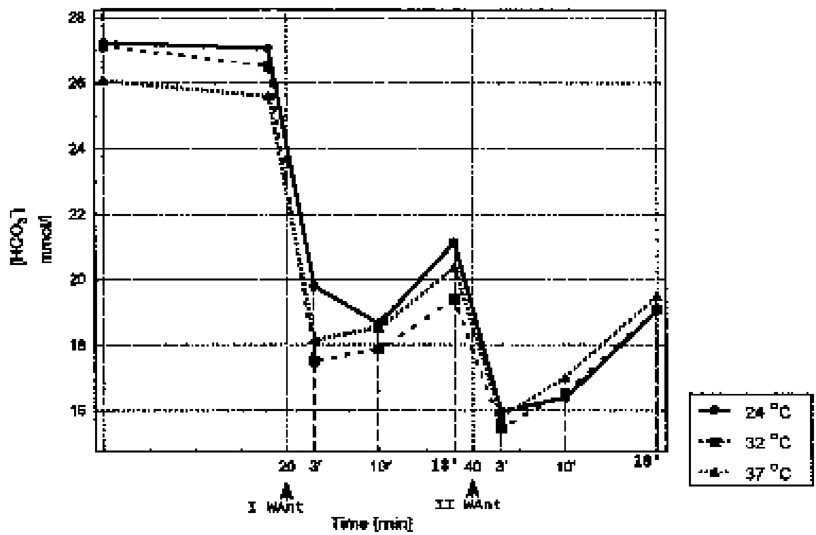


Fig. 14. Concentration of HCO_3^- ions during the experiment

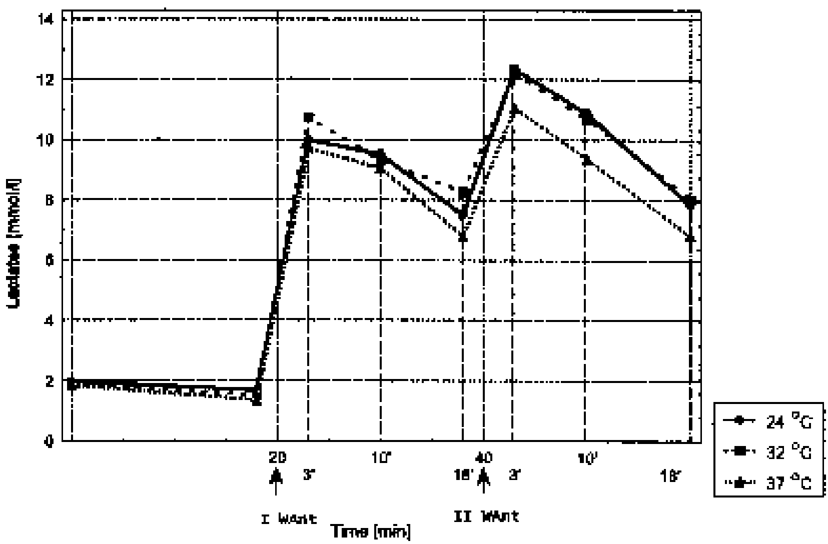


Fig. 15. Concentration of lactates during the experiment

To supplement the study of parameters of acid-alkaline equilibrium, we present the analysis of changes of mean values of $[HCO_3]^-$ (Fig. 14). It was expected that concentration of this ion will get smaller after the efforts. Really, one can ascertain, that after the first and second effort (receiving 3 and 6) the reduction of $[HCO_3]^-$ is

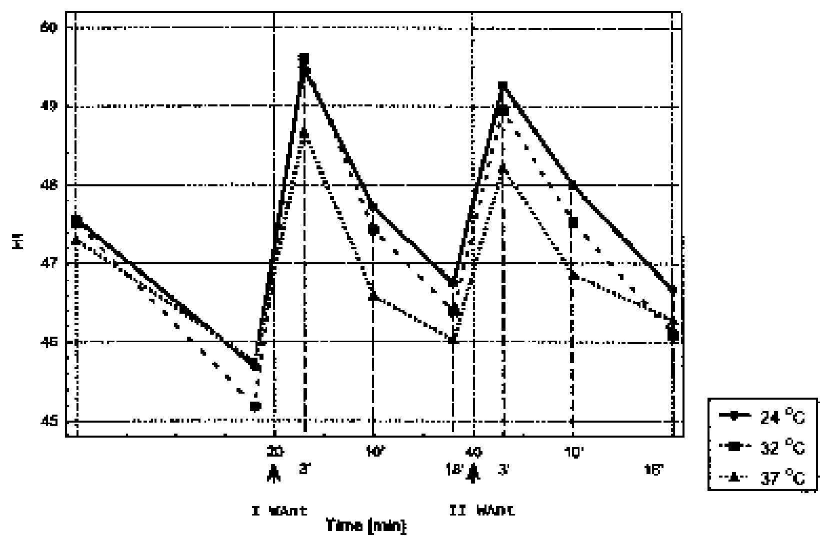


Fig. 16. Hematocrite number during the experiment

considerable. As it is known, these ions are component of buffer reacting in the "first throw" on [H⁺] changes. The smallest concentration of $[HCO_3]$ was recorded after the efforts at temperature 32°C. Simultaneously, at this temperature the decrease of buffering alkaline was most considerable.

Fig.15 shows the changes of mean values of lactate concentration. The pattern of changes is like that of the changes of $[H^+]$. Detailed analysis allows to observe certain differences, namely: at all three ambient temperatures the lactates concentration is higher after the second effort rather than after the first, while the increase of LA concentration is greater after the first effort. It is worthwhile to remind that $[H^+]$ after the second effort was smaller than after the first. The analysis of sample received in the 10th minute after the first effort shows that LA level decreases more slowly than $[H^+]$, especially at temperature 24 and 37°C.

The changes of mean values of hematocrite number (Fig.16) points to the increase of Hct after both efforts. At the temperature 37°C Htc drops clearly in relation to lower temperatures; maximum values were lower than at remaining temperatures (this phenomenon is connected with proportional changes of volume of plasma). In the case of Hct values, the standard deviations and intragroup variability are similar.

Figures 17, 18 and 19 show the average levels of $[K^+]$, $[Na^+]$ and $[Cl^-]$. Interpretation of these data is however not so univocal as in preceding cases, especially with regards to research aimed to find the relations between the regularity and ambient temperature effects. Interpretation is made difficult or may lead to false assumptions because the degree of plasma condensation is not considered. Thus, after the efforts the reduction of concentration of $[K^+]$ was observed at all considered tem-

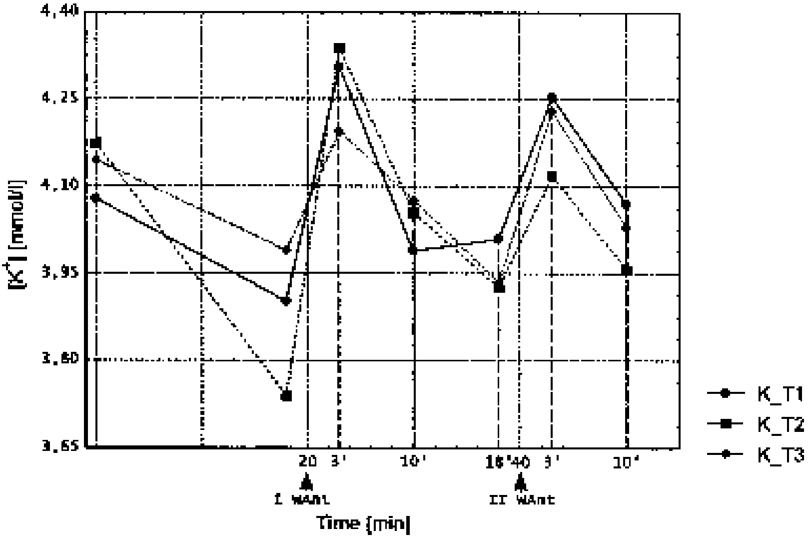


Fig. 17. Concentration of K⁻ ions during the experiment

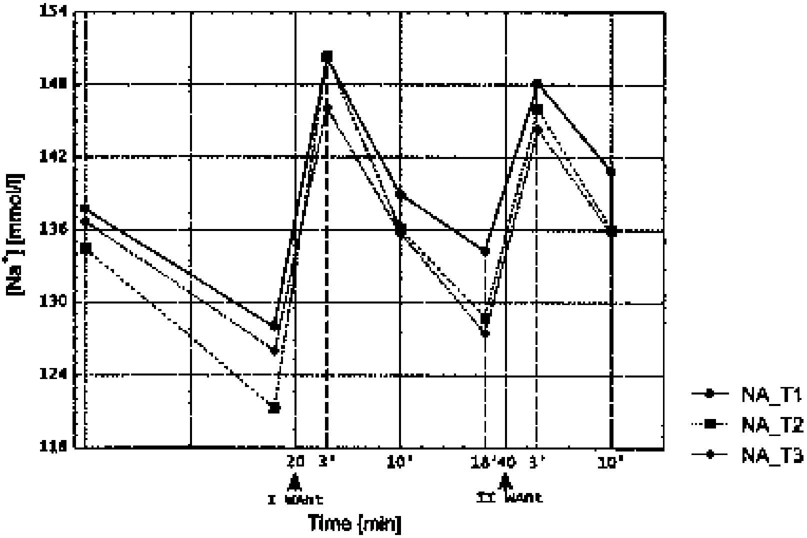


Fig. 18. Concentration of Na^+ ions during the experiment

peratures. At the temperature 24°C it was greatest in the 10th minute after the first effort (over 0,4 SD). The highest average [K^+] was noted at the temperature 37°C (2) and at temperature 24°C (in eighth to receiving), while the lowest was found after the second effort at the temperature 32°C. It is interesting that changes of this parameter are similar at extreme temperatures (24 and 37°C), while most considerable

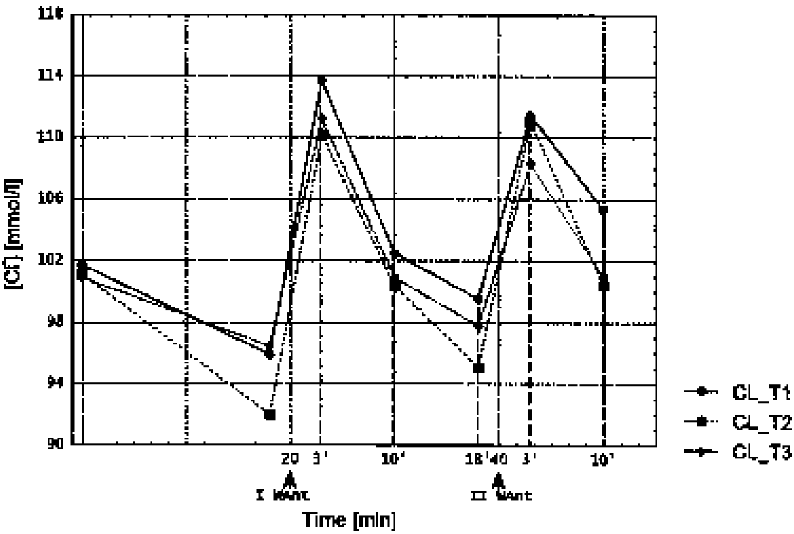


Fig. 19. Concentration of Cl^- ions during the experiment

differences are found at the temperature 32°C. The lowest relative lowering of [K^+] was noted after the first effort, while the highest increase was registered after the second one. Taking under attention fact, that after efforts volume of plasma grows smaller, one can acknowledge, that after effort [K^+] really grows smaller.

The similar pattern can be observed in the case of [Na^+] concentration. The lowest concentrations were found at the temperature 32°C, but after an effort it increased considerably; the changes at the temperature 37°C were similar. Complementarily of these two cautions is confirmed by the fact that in after-efforts samples the concentration of ions K+ decreased, while of Na^+ — increased (Fig. 18, 19). It is difficult to interpret the real changes of [Na^+] concentration, because of the condensation of plasma after effort. Additionally, this difficulties are further complicated by the fact that a certain quantity of electrolytes can be removed from organism in the process of perspiration. This problem will be then discussed.

Changes of [Cl^-] give different and irregular patterns at all external temperatures. During the third intake, it clearly grows at the temperature 24 and 37°C, while at the temperature 32°C — it gets smaller. In receiving sixth [Cl^-] turn it increased at the temperature 32 and 37°C, but in the seventh — it grew smaller. At the temperature of 24°C this process lasted longer, until the beginning of the seventh cycle. In general, the changes described above were not too large.

It seems, that the reason for such reaction, as well as generally the least "correct" pattern of electrolytes changes in individual reactions may vary considerably. As we can observe, regardless of the direction of changes of mean values in all ions concentration measurements, the values of individual results ranged plus to minus and so in some examined persons these values increased, while in other — they decreased. This fact suggests the need for a more detailed analysis based on the criterion taking into account the possibility of combining training, as (hypothetically) the main exogenous factor determining the physiological adaptation of an organism. At the same time it becomes a serious methodological problem in relation to investigations in which results obtained from small samples are generalised on the ground of mean values.

Because of that we decided to analyse select parameters (most representative in two groups separated according to the criterion of "maximum power", as joint abilities, all ezogenic and endogenic (genetic) predispositions conditioning efficiency of anaerobic energetic processes and their co-ordination (e.g. of speed of muscle mobilisation, nervous-muscular co-ordination, etc).

Typological analysis

As it was mentioned above, the examined persons were divided into two groups according to the criterion of maximum power. Group 1 included individuals whose maximum power was below 800 W, in the second group were these who exceeded 800 W. With regard to this criterion, the differences between the group members

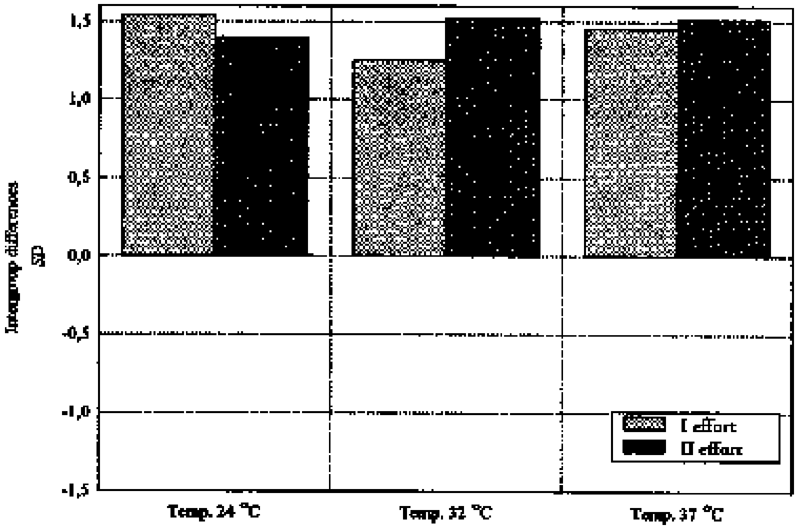


Fig. 20. Inter-group differences of maximal power at different temperatures

were very large (Fig. 20). The second group reached considerably higher values of maximum power (of about 1,2–1,5 SD) than the first one. One should remember, however, that this value was a dividing criterion. It is interesting that at the temperature 32 and 37°C the differences between the group members after the second effort were greater than in the first. The opposite tendency appeared at 24°C.

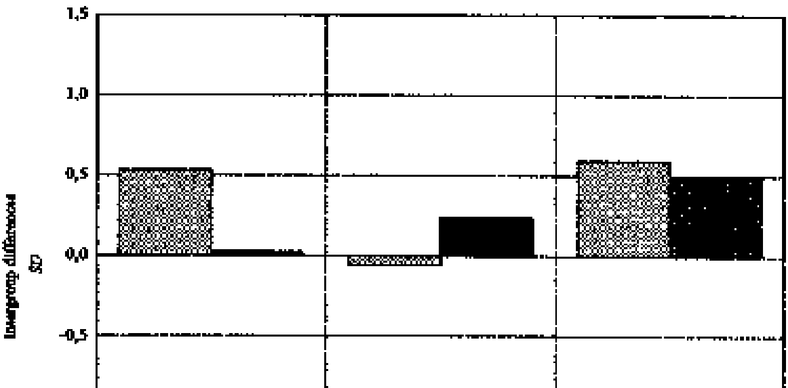


Fig. 21. Inter-group differences of maximal relative power at different temperatures

As far as the values of maximum relative power were concerned (Fig. 21) the second group obtained better results, especially at the temperature 37°C during the two efforts. At the temperature 32°C the results after the second effort were slightly better and at the temperature 24°C — after the first effort. These differences are, however, much smaller, than those expressed in absolute values.

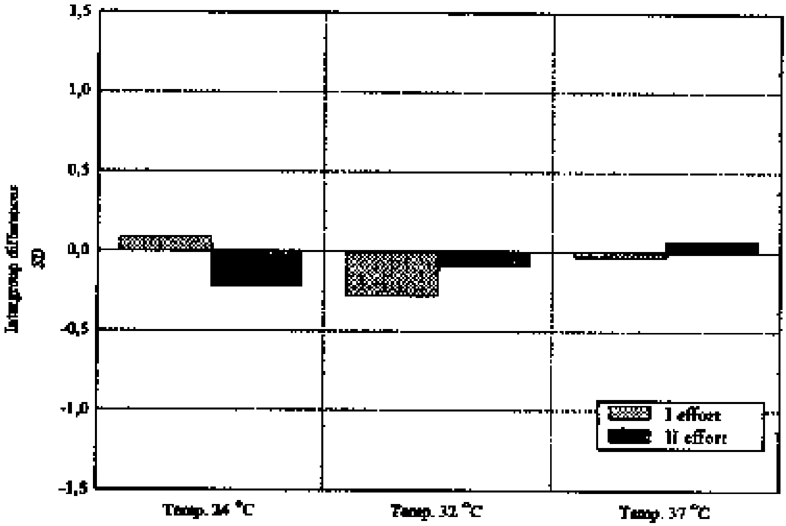


Fig. 22. Intergroup differences of average power at different temperatures

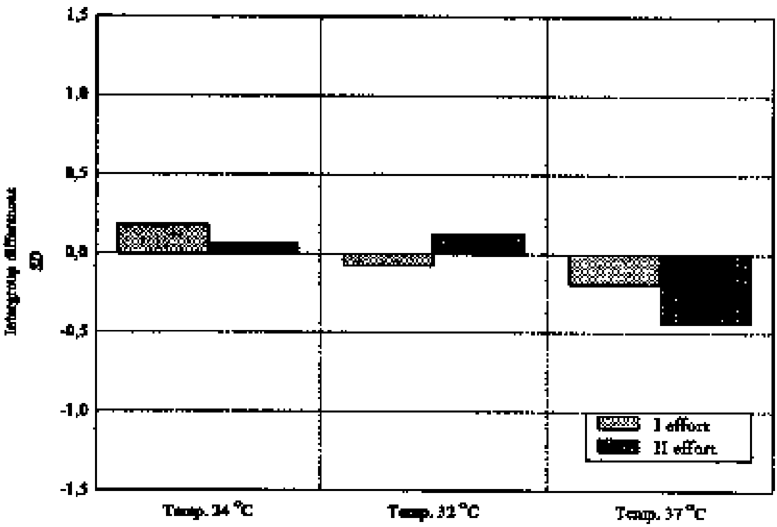


Fig. 23. Intergroup differences of number of rotations at different temperatures

Minimum differences of average power (Fig. 22) follow a different pattern, more often the values were even lower in the second group (mostly at the temperature 32°C). With regard to this parameter, thus compared groups seem homogeneous.

Let us also consider the number of rotations (Fig. 23), which at the temperature 37°C during the second effort was clearly smaller in the group with higher values of

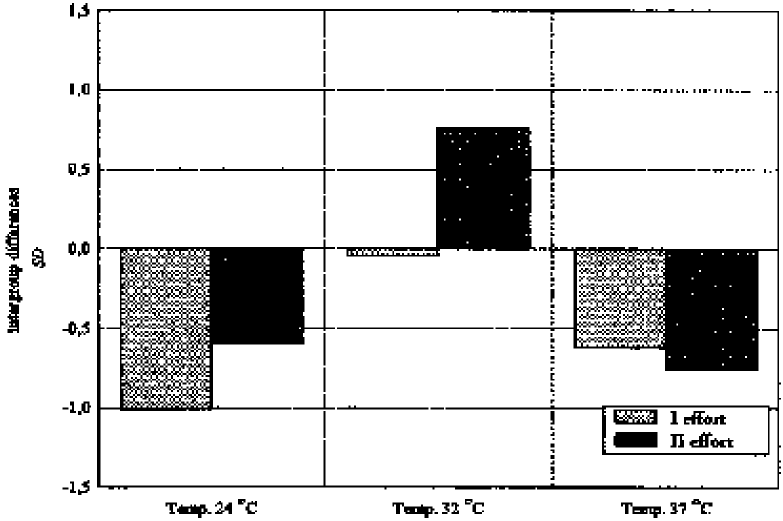


Fig. 24. Intergroup differences of Time of achieving the maximum power at different temperatures

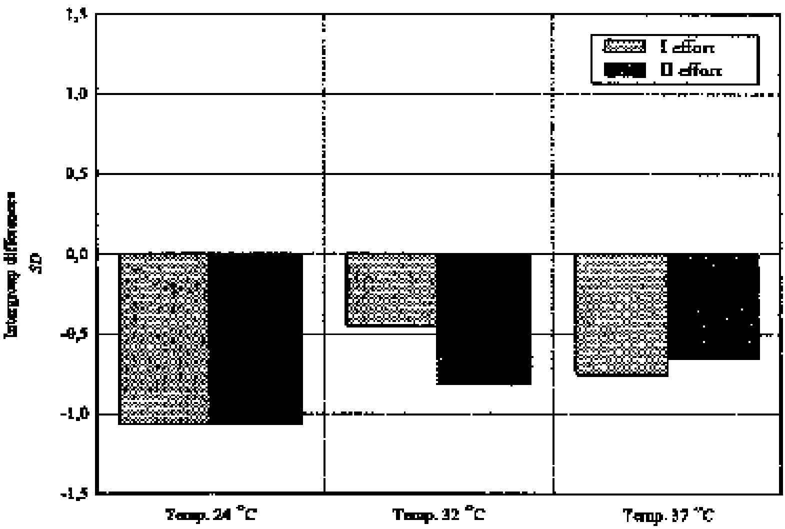


Fig. 25. Intergruop differences of time of maintaining the maximum power at different temperatures

maximum power (both absolute and relative). Higher power was obtained by this group at smaller number of rotations (because of differences in body mass and — in consequence — the magnitude of resistance).

It is interesting (Fig. 24) that investigated persons from the second group more quickly obtained the maximum power, although it was considerably higher.

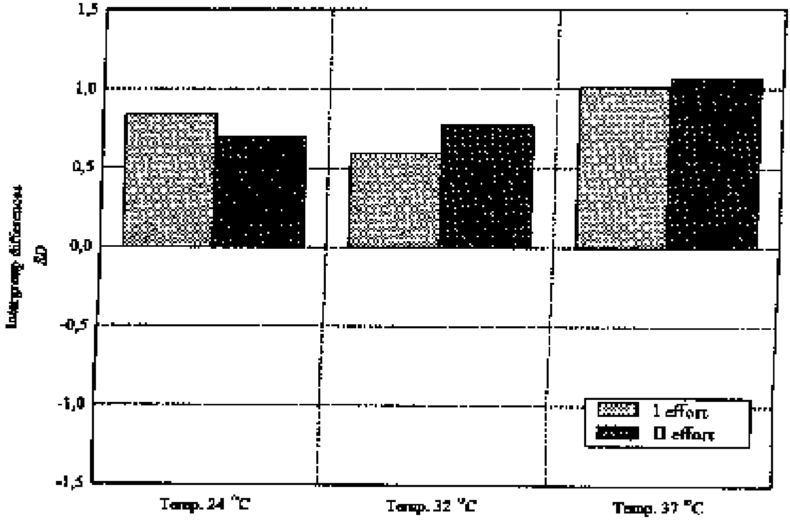


Fig. 26. Intergroup differences of decrease of relative power at different temperatures

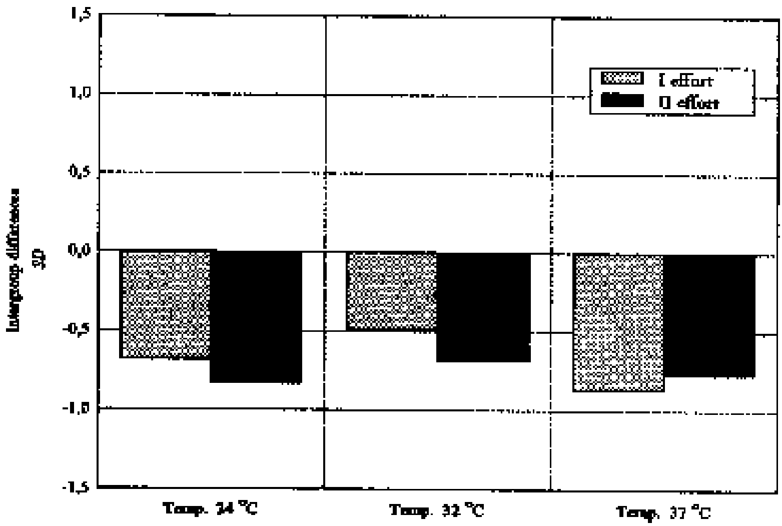


Fig. 27. Intergroup differences of effort HR at different temperatures

The time of maintaining the maximum power was shorter (which seems self-evident) by the examined persons from the second group: that confirms this well-known biological regularity mentioned earlier. Together with temperature increase (especially in the second efforts), this time is relatively prolonged in the second group.

Complementary to time of maintaining the maximum power were intergroup differences of decrease of relative power (Fig. 26). This parameter showed clearly (over one SD) the higher level in second group, in relation to this the decrease was quicker (especially at 37°C).

The normalised intergroup differences of HR are presented in Fig. 27. Examined persons from the second groups had in all experiment the smaller frequency of HR than those the first group. These differences, most predominant at 37°C, were still considerable.

To illustrate the differences of average body temperatures between the group members we analysed the skin temperature as probably the most typical state of disturbances to thermo-regulation.

And so, the similar pattern of changes in the whole group (Fig. 28) involves (outside temperature 24°C) Ts lowering after efforts, yet the scale and tendencies of changes in each group were different.

The second group (with higher level of maximum power) had higher level of Ts than the first group at the temperature 24°C, the differences were rather stable and only little increased in the next measurements. This changes were greatest (0,8-1,4 SD) at the temperature 32°C and resulted from higher values of this parameter

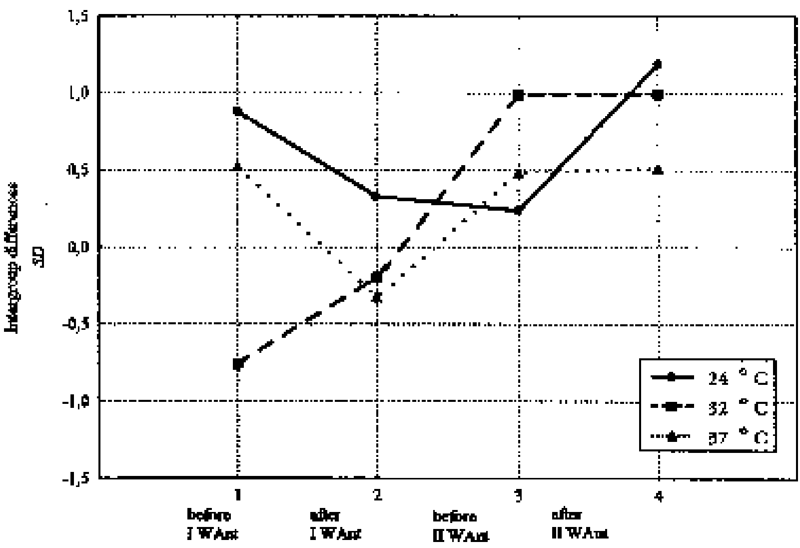


Fig. 28. Intergroup differences of skin temperature at different temperatures

in the first group and from bigger increases in after-effort measurements. At the temperature 37°C the pattern of differences is reversed (almost as the negative — but slightly). The first group showed lower average weighed temperature of skin (Ts), while these differences increased in a smaller degree in the following efforts and were the least the temperature 37°C.

Recapitulation and discussion

Since the publications on the subject discussed in the present study are rather scarce, as it was emphasised in one of the recent works (Inbar et. al. 1996), the comparison with results obtained by other authors is possible only for ambient temperatures of 24°C, as at this temperature most studies relating to Wingate Test were carried out. The group of persons examined by us to check the maximal power and relative power achieved considerably higher results in relation to not trained men at the same age (Inbar et. al. 1996). As we already mentioned, this group cannot be regarded as representative. Precise control of mechanical power parameters allows us to conclude that the number of rotations, maximum power and relative power in following efforts show distinct dependence on ambient temperatures. At the temperature 24°C the higher average of these parameters was registered during the second effort, while at the temperature 32 and 37°C — in the first one. One should remember, that in the experiment before the Wingate Test they did not have any warming -up, quite on purpose. It is possible, that in certain degree that was done during the first effort. At the temperature 32°C, and especially 37°C, the improvement of circulation and increase of internal temperature (especially muscular) followed passively (passive warming). Thus we can conclude that the results of first Wingate Test from the very start reflected the maximum possibilities of investigated individuals. This conclusion is very important from the point of view of sports-practice (adjusting the warming up to temperature of environment). Values of "relative average power" did not yield the relation presented above, because higher values were reached during the second efforts regardless of the ambient temperature. It follows then that the capacity of anaerobic sources depends on environmental factors in a smaller degree than the developed maximum power. We should emphasise that the highest values in both efforts were recorded at the temperature 32°C. At that temperature the differences of maximum power was the greatest. One should accept that in maximum efforts with short time of duration, the heat loss through the skin (at least to a certain limit) does not impact on test results: that observation agrees well with the sport practice.

Both the time of attaining the maximum power and the average time of its maintenance during the first effort were similar at all examined temperatures of environment. It seems, that external temperature does not impact on the first tests results, unlike the second one. The time of obtaining the maximum power increases with temperature; at the same time individual differences become more marked. As far as the average time of maintaining the maximum power is concerned, the temperature of 32°C proved to be the optimal one for obtaining the best results in Wingate Test; regardless of the test sequence. Thus obtained mean values of before-effort HR oscillate in the range 74–78 per minute. This values are much lower than in other investigations (Dotan and Bar-Or 1980). However the examined persons there were children at the age of 10–12; in which HR is higher, besides the students examined by us were engaged in moderate physical activities. The mean effort HR after the first attempt was lower than after the second one, the individual differences were significant (143–204 min^{-1}). The majority of examined persons did not obtain the maximum HR typical for short efforts of maximum intensity (did not bring to light their own possibilities). That is most likely connected also with motivation which influences the results, as mentioned by Geron and Inbar (1980) and Sargeant (1990).

Important parameters measured before and after the efforts were the skin, rectal and muscular temperatures. At the temperature of 32 and 37°C the average weighed skin temperature was lower after efforts, while after the second effort this value would be slightly higher than after the first. This phenomenon is connected with the process of perspiring: just because at temperatures 32 and 37°C the decrease of body mass was the greatest. At the temperature of 24°C the decrease of skin temperatures was considerably smaller and so was the decrease of body mass (at such temperatures perspiration is not so intensive). The changes of rectal temperature showed an opposite tendency [increased after an effort] due to intensive endogenic heat production during effort. However this temperature is most stable, and its increase after the effort does not limit the ability of an organism to function.

Muscular temperature reached the lowest values at the ambient temperaturev24°C, a little higher AT 32°C, and the highest at 37°C. Regardless of the ambient temperature, the starting values of Tm before the second Wingate Test were always higher in relation to those measured before the first effort. In the case of the temperature 24°C, the starting muscular temperature influenced the results of Wingate Test. This agrees well with the reports of Hill (1956), Clarke and Royce (1962); Mathews et. al. (1964); Frank (1972); King et. al. (1970). At higher temperatures of environment this dependence is not so marked: obviously the average relative power is always higher during the second effort, while the highest values are recorded at the temperature of 32°C, not 37°C (where the highest muscular temperature was measured).

These results differ from the data presented by Dotan and Bar-Or (1980): they did not find that the climatic conditions should effect the results of Wingate Test. These Authors examined the children at the age of 10-12, testing them in thermoneutral environment (22–23°C, 55–60% h. rel.), hotly dry (38–39°C, 25–35% h. rel.) and warmly moist (30°C, 85–90% h. rel.). It is very difficult, however, to compare the efficiency of thermo-regulation mechanisms in children and adults, especially in the light of the fact that these authors did not separate the temperature factors from relative moisture, which can produce different effects.

After-effort changes of parameters of acid-alkaline equilibrium were in concordance with expectations. The highest average value of [H^+] was found in samples taken in the third minute after the effort (the first as well as the second), with simultaneous greatest decrease of buffering alkaline (BE). In those samples one could observe the least concentration of [HCO_3^-], a component of carbonate buffer. The lowest concentration of this ion and the greatest decrease of buffering alkaline happened after efforts at the temperature 32°C. We should bear in mind that this temperature provided most favourable conditions for the tests, while the and results obtained by the examined persons (maximum power, average power) were the best.

The pattern of average [La] changes was in concordance with that of [H^+] changes, however the lactates concentration was higher after the second effort, and dropped more slowly than [H^+], instead it did not increase to any higher level after the second effort, while the utilisation of the former was quicker. It points out to the fact that 20 minutes' pause between tests is too short for entire recovery. Presented patterns of changes of described parameters are in concordance with the data provided by Markiewicz and Cholewa (1979), where the 30 minutes' break proved also too short for removing the effects of changes produced by maximum effort.

It is well known, the efficiency of glycolitic mechanism will influence the developed anaerobic power, especially the concentration of lactate dehydrogenase (Esbjornsson 1996). Adult men have greater ability of generating energy on anaerobic track than women or children, just because of higher efficiency of glycolitic mechanism (Gaul et. al. 1995). Anaerobic nature of the effort is confirmed, among the others, by concentration of LA in blood (Jacobs et. al. 1982). The average concentrations of [H^+] and [La] obtained in the present study displayed lower values than those in Karlson and Saltin (1970) report. In the 10^{th} minute after the effort these authors noted in men [H^+] at 66,1 mol/l and La^- 14,2 mol/l. The relevant values in our study were 53, 3 for [H^+] and 9,5 mol/l for [La] at the temperature of 24°C. This difference can result from different time of Wingate Test duration in our study (the time was about 20 of seconds). Jacobs et. al. (1982) reported, the time of test duration can limit the decrease of glycolitic source. Additionally, the highest concentration of lactates noted in the third minute after the effort does not prove that these would occur between the 5^{th} and 9^{th} minute from the end of the effort (Inbar at al. 1983), but indeed in some individuals the highest concentration [La] were registered in the 10^{th} minute after the effort.

The results of our study show that the average [H^+] and [La] dropped more quickly at increased ambient temperatures (32, 37°C) during 20 minutes' rest. This confirms once again a well-known fact of quicker mobilisation of cardio-respiratory and nervous systems and of the function of endocrine glands in conditions of raised temperature. That also agrees well with Van Hoff rule, whereby at increased temperatures the chemical processes proceed at a higher rate.

Lower values of [H^+] noted at 37°C throughout the experiment (especially after the second effort) can partly confirm the above statement, as well as that about the limitation of possibility of development of large anaerobic power (especially in second effort) due to high temperature of environment.

Interpretation of electrolyte changes presents many problems, both in the case of our study and in literature reports (it is well known that intracellular acidifying enhances the penetrability of cellular membrane for some electrolytes and discriminates the activity of natrium-kalium pump). At the same time, the interpretation of results is made difficult because of changes in the volume of plasma and secretions from sweat (Markiewicz and Cholewa 1979). After-effort increase of [Na^+] and [K^+] was noted by Lindinger et. al. (1992). They interpret this fact as the release of active muscles — ion K^+. In the next phase [K^+] would have to be caught through muscles and other tissues (Medbo and Sejersted 1990). Markiewicz and Cholewa (1979) noted the increase of [Na^+] and no changes in [K^+]. These data do not take into account the changes in the volume of plasma. They agree well with experimental results, where the decrease of concentration of [K^-] was registered after efforts, [and increase of [Na^+]], but at the temperature of 24°C these changes were least marked. As far as the changes of volume of plasma are concerned, the quoted authors noted the increase of [K^+] and lack of changes in [Na^+]. In our study we observed the decrease in concentrations of [Na^+], [K^+], and [Cl^-] for all temperatures of environment in after-effort samples of blood, taking into consideration the changes of plasma volume.

The analysis of our results and those presented in literatures suggests, that those divergences and inconsistencies may be the consequence of research methodology: small groups of examined persons (a dozen or so), arithmetic means analysis, and the correlation coefficients burdened by considerable standard error, because of huge variety of individual reactions. Variability may reach positive and negative values — the magnitude can be accidental and disregard the differences of individual reactions.

Typological analysis of selected parameters presented in the present work confirms the existence of intergroup differences. While testing people it is impossible to sort a homogeneous groups, therefore, the study reflects a variety of individual changes of each parameters, due to different predispositions or a degree of training.

As the group was divided depending on the criterion of maximum anaerobic power, we could recognise the different tendencies and reactions of particular individuals. With regard to maximum power and relative power as the criteria, the second group obtained considerably higher values. Greater inter-group differences were found at the temperature 32 and 37°C in the second effort; which can be the result of better efficiencies of thermoregulation mechanisms in examined persons from this group — which can be the result of training. It confirms the earlier suggestion about better efficiencies of these mechanisms in the examined persons trained beforehand. Smaller inter-group differences of relative values than absolute ones confirm the relation between obtained Wingate-Test results and body mass (Sargeant 1990, Meltzer 1996).

As far as the average power or the number of rotations during the Test are concerned, the compared groups did not differ. AT the temperature of 37°C the second group obtained however considerably higher values of maximum power (both absolute and relative) at smaller number of rotations.

The time of obtaining the of maximum power was shorter for the examined persons from the second group. It can be the result of both a higher degree of trainability and greater numbers of fast muscle fibres (genetic factor). It is difficult to account for the fact of slower developing of maximum power by this group during the second effort at the temperature of 37°C. As mentioned above, the shorter time of obtaining the maximum power, the shorter time of its maintenance. The examined persons from the second group attained maximum power for shorter periods and, interesting enough, this time was relatively prolonged with the ambient temperature (especially during the second effort). It can be due to better functioning of thermoregulation mechanisms in persons developing higher anaerobic power. The differences of decrease of relative power followed the same pattern as the time of maintaining the maximum power. The examined persons from the second group lost their relative power more quickly. This a confirms a well-known biological regularity (Szopa et. al. 1996), that the greater the dynamics of developing the maximum value, the shorter is time of its maintenance and greater dynamics of regress. The inter-group differences of HR are very marked. Lower heart rate at all ambient temperatures could be found in the examined persons from the second group, especially at the temperature of 37°C. It points out to higher degree of trainability of individuals from the second group and the fact that they do not use their potential to the full (the problem of motivation). Among many investigated biochemical parameters, distinct changes were found [H^+] an [La]. Though the pattern of [H^+] changes is the same in both groups (which is self-evident), yet the scale is different (after-effort increases of [H^+] are smaller in the first group). This agrees well with smaller production of lactic acid, and with smaller possibilities of developing the anaerobic power. In the second group increase and decrease levels were more significant. Small increase of [H^+] at the temperature of 37°C after the second effort can be caused by smaller effort capacity during the test repeated at comparatively short time interval.

We have to pay some attention to the disproportion of standard deviations in after-effort measurements. They just cause, as it was mentioned in the earlier sections, the disproportion of results — especially at the temperature 32 and 37°C. Generally, the group with the higher level of power is characterised by greater [H^+] production and quicker recovery.

Standardised levels of [La] concentration displayed large inter-group variability. It is the same as the pattern of [H^+] changes: the fact that the second group had higher [La] is easy to explain when we refer to processes of obtaining energy in the efforts of short duration. Neutralisation of lactic acid in the examined persons from the second group was much slower than in the first group: differences in [La] among both groups were probably too large to be compensate in such short time. Looking at changes of this parameter in relation to the ambient temperature, we observe that the lowest increase of lactates in after-effort conditions was noted at the temperature of 37°C. At that temperature the decrease of its concentration was quickest. This fact can be explained in a different way. Maybe the improvement of circulation and of certain biochemical reactions may counterbalance the differences resulting from different degree of training. This decrease is borne out by inter-group differences disappearing with an increasing of temperature: the greatest at the temperature of 24°C, a little smaller at 32°C and the smallest 37°C. This differentiation becomes apparent starting from the fifth intake, which points out to greater role of second effort manifestation of those differences, such as the degree of training. That those results are not absolutely certain is the result of group non-homogeneity. One should seriously consider, whether it is not an incorrect statement that physiological reactions are — at least regarding their patterns — identical in the people. Genetic and environmental conditions cause huge individual differences. Presented results are limited only to the examined group and should not be generalised to cover all population.

Conclusions

1. Ambient temperature had a definite impact on mechanical, functional and biochemical parameters during short-lasting efforts of maximal intensity. The temperature 32° C seems optimal for getting the best results.

2. Twenty minutes' rest occured too short to full recovery after the effort. It had, therefore, no influence on the results on the results of repeated efforts.

3. Individual differences of physiological responses to repeated effort of maximal intensity were significant, which means that sports training has a distinct influence on them. While testing people one should take into account the heterogeneity of investigated groups.

4. Existing continuos variability of functional traits allowed us to draw the conclusion that in human physiology studies we should apply the same methodological rules as in other sciences: testing small numbers of people will produce incorrect results, and these results must not be further generalised and referred to the whole population.

REFERENCES

Bar-Or O. 1978. *A new anaerobic capacity test characteristic and application*. The World Congress in Sport Maed. Brasilia.

Bouchard C., Boulay M. R., Simoneau J. A., Lortie G., Perusse L. 1988. *Heredity and trainability aerobic and anaerobic performances*. An update. Sports Med., vol. 5.

Clarke D. H., Royce J. 1962. *Rate of muscle tension development and release under extreme temperatures*. Int. Z. Angew. Physiol. Einsch. Arbeitsphysiol., vol 19.

Dotan R., Bar-Or O. 1980. *Climatic heat stress and performance in the Wingate Anaerobic Test.* Europ. J. Appl. Physiol., vol 44.

Edwards R. H. , Harris R. C., Hultman E., Kaiser L., Koh D., Nordesjo L. O. 1972. *Effects of temperature on muscle energy, metabolism and endurance during successive isometric contractions sustained to fatigue, of the quadriceps muscle in man.* J. Physiol. No 220.

Esbjörnsson L., Holm M., Sylven J., Jansson Ch. 1996. *Different responses of skeletal muscle following sprint training in men and woman.* Eur. J. Appl. Physiol., vol 74.

Frank B. D. 1972. *Physical worm-up.* In: Morgan W. P. (ed). *Ergogenic aids and muscular performance.* Academic Press, London-New York.

Gaul C.A.,Docherty D.,Cicchini R. 1995. *Differences in Anaerobic Performance Between Boys and Man.*Int.J. Sports Med., vol.16, No 7.

Geron E., Inbar O. 1980. *Motivation and anaerobic performance.* In: *Art and science of coaching, ed.* Simri U., 107-17. Netarya, Israel: Wingate Institute.

Harrison M.H.,Graveney M.J.,Cochrane L.A.1982. *Some sources of error in the calculation of relative change in plasma volume.* Eur.J. of Physiol. and Occup. Physiol.vol 50.

Heberstreit H., Meyer F., Htay-Htay G. J. F. Heigenhauser, Bar-Or O. 1996. Europ. J. Appl. Physiol., vol 72.

Hill A.V. 1956.*The design of muscles.*Br. Med. Bull. vol 12.

Inbar O., Bar-Or O., Skinner J. S. 1996. *The Wingate Anaerobic Test.* Human Kinetics. Publ. Champaign, Ill.

Inbar O.,Rotstein A.,Jacobs I.,Kaiser P.,Dlin R.,Dotan R.1983. *The effect of alkaline treatments on short-term maximal exercise.* J.Sports Sc. vol 1.

Jacobs J., Bar-Or O., Karlson J., Dotan R., Pitesch, Kaiser P., and Inbar O. 1982. *Changes in muscle metabolites in females with 30-s exhaustive exercise.* Med. Sc. Sport Exercise, vol. 14, no. 6.

Karlson J., Saltin B. 1970. *Lactate, ATP, and CP in working muscles during exhaustive exercise in man.* J. Appl. Physiol. vol 29.

King P.G.,Mendryk S.,Reid D.C.,Kehy R.1970. *The effect of actively increased muscle temperature on grip strength.* Med. Sci.Sports vol 2.

Kubica R.,Nielsen B.,Bonnesen A.,Rasmussen I.B.,Stokłosa J.,Wilk B.1983. *Relationship Between Plasma Volume Reduction and Plasma Electrolyte Changes After Prolonged Bicycle Exercise, Passive Heating and Diuretic Dehydration.* Acta Physiol. Pol. 5-6.

Lindinger M.J.,Heigenhauser G.J.F.,Mc Kelvie R.S.,Jones N.L.1992.*Blood ion regulation during repeated maximal exercise and recovery in humans.* Am J Physiol vol 262.

Mainwodd G., Cechetto D. V. 1980. *The effect of bicarbonate concentration on fatigue and recovery in isolated rat diaphragm.* Com. J. Physiol. Pharmacol., vol 58.

Markiewicz K., Cholewa M. 1979. *Dynamics of acid-alkaline equilibrium during physical effort and restitution.* Acta Physiol. Pol., vol 30, supplement 19 (in Polish, Engl. Summ.).

Mathews D.K.,Stacy R.W., Hoover G.N. 1964. *Physiology of muscular activity and exercise.*Ronald Press, New York.

Medbo J.I., Sejersted O.M. 1990. *Plasma potassium changes with high intensity exercise.* J. Physiol. No 421.

Meltzer D. E. 1996. *Body-mass dependence of age-related deterioration in human muscular function.* J. Appl. Physiol. Vol 80 (4).

Nielsen B.,Kubica R.,Bonnesen A.,Rasmussen I.B.,Stokłosa J.,Wilk B.1981.*Physical work capacity after dehydration and hypothermia: Comparison of the effect of exercise versus passive heating and sauna diuretic dehydration* .Scand J. Sports Sc.vol 3.

Parkhouse W. S., Mc Kenzie D. C. 1984. *Possible contribution of skeletal muscle buffers to enhanced anaerobic performance*: A Brief review. Med. Sc. Sports Exerc., vol 16.

Sargeant A. J. 1990. *Measurement of Short-Term (Anaerobic) Power.* International Union of Biological Sciences.
Sharp R. L., Stanford P. D., Beran L., Runyan W. S. 1986. *Effects of altered acid-base status on performance of two types of anaerobic exercise tests.* Med. Sc. Sports Exerc., vol 18.
Simoneau J. A., Lortic G., Leblanc G., Bouchard C. 1986. *Anaerobic alactacid work capacity in adapted and biological Siblings.* In: *Sport and Human Genetics*, Human Kinetics Publ., Champaing, Ill.
Szopa J., Mleczko E., Żak S. 1996.Background of Kinesiology. Pol. Sc. Edit., Warszawa-Kraków (in Polish).