

# INFLUENCE OF TWO HIGH-INTENSITY INTERMITTENT TRAINING PROGRAMMES ON ANAEROBIC CAPACITY IN HUMANS

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**ABSTRACT:** The aim of this work was to determine the influence of a maximal effort training programme with variation of the pedalling rate on the anaerobic capacity, post-exercise maximal concentration of lactic acid (LA) and acid-alkali balance changes in the capillary blood. Identification of the dependence between the lactic acid concentration and the anaerobic capacity produced in the Wingate test was also the goal. The hypothesis that cycloergometer training consisting of maximal efforts with a load equal to 10% of body weight (BW) will elicit bigger changes of measured values in comparison to training with a load of 5% BW was verified. Twenty non-athletes, students of UPE took part in the study. They were divided into 2 groups. The first group (M10; n=9) performed maximal efforts with a load equal to 10% of body weight (BW). The second group (M5; n=11) performed maximal efforts with a load of 5% BW. Control measurements of anaerobic capacity (Wingate test) were taken every Monday: before the test (0), during 4 weeks of training (1-4) and for 2 weeks after the test (5-6). Blood for the determination of lactic acid concentration and acid-alkali balance was taken from the fingertip before performing the Wingate test – in the 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup> and 30<sup>th</sup> resting minute. Changes of maximal power ( $P_{max}$ ) were not statistically significant in either group. Significant differences were found between the two groups after the second week of rest. For mean power ( $P_m$ ) the most important changes were noted in the first week from training (M10 – 6.5%; M5 – 11.0%). No significant differences were found between groups. Average values of the individual LA concentration peak (the highest LA concentration occurring after the Wingate test for each individual) changed significantly in group M10 from  $15.233 \pm 2.367$  mmol/l in the measurement made before training to  $12.340 \pm 2.353$  mmol/l in the measurement taken 2 weeks after training. Group M5 is characterised by a change of this factor after 4 weeks of training from  $15.109 \pm 1.739$  (before tests) to  $13.491 \pm 2.098$  mmol/l. The scarcity of significant changes between groups indicates that the pedalling rate does not influence the anaerobic capacity. A surprising observation was the lactic acid concentration lowering in the Wingate test performed after 4 weeks of maximal effort training in relation to the LA values obtained before the experiment began.

**KEY WORDS:** anaerobic capacity, blood lactate, cycle ergometer training, power output, Wingate test

## INTRODUCTION

The Wingate test and lactic acid (LA) concentration measurement after maximal effort are frequently used for anaerobic capacity evaluation. The anaerobic capacity determinants in the Wingate test are maximal power, mean power and fatigue index. Some discordant data considering changes of power produced in the Wingate test consisting of short but maximal intensity efforts on the cycloergometer are presented in the references. Allemeier et al. [1], Esbjörnsson et al. [10], Esbjörnsson Liljedahl et al. [11], Jacobs et al. [20] and Rodas et al. [37] reported that sprint training on the cycloergometer did not cause changes of power measured in the Wingate test. In the work of Parry et al. [33] no post-training changes of the peak power or average power measured in the Wingate test were observed in a group of subjects practising every day for 2 weeks. These values increased after 30 s activity by 20 and 14% respectively in the second group, which had a 2-day break between training sessions. Also in the work of O'Connor [32]

some significant or insignificant post-training changes of maximal power were noted depending on the exercises performed. Nonetheless, in the works of Linossier et al. [22] and Stathis et al. [42] brief efforts with high intensity performed on the cycloergometer elicited the maximal power and increase of performed work.

It is believed that the post-exercise concentration of lactic acid (LA) is an indicator of adaptation to very intense training [16,38]. McRae et al. [36] stated that the LA production depends on the effort intensity. They suggested that lactic acid generation is lower after effort of low intensity and higher after training of higher intensity. In the works of Linossier et al. [22] and Denis et al. [9] it was ascertained that sprint practice causes a higher concentration of lactic acid. In the study of Sharp et al. [39] the lactate accumulation grew crucially after the sprint test, while the pH in muscles did not change. On the other hand, in the works of Pary et al. [33] and Rodas et al. [37] a decrease

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of intra-muscular LA concentration was noted simultaneously with its concentration growth in the capillary blood and a lack of pH change after compound training (15 and 30 s maximal efforts).

According to Lutostawska et al. [24] the relation between lactic acid and anaerobic work may change contingently upon applied training; however, there are only a few works relating to this subject in the literature. Significant correlations of lactic acid concentration and anaerobic test results were reported in the papers of Berg and Keul [5], Fujitsuka et al. [13], Granier et al. [14], Linossier et al. [22], Lutostawska et al. [24] and Tamayo et al. [43]. Gratas-Delamarche et al. [15] found a significant correlation between the LA concentration and work performed in the Wingate test in female sprinters but did not observe such a correlation in male athletes. No relation between LA concentration and power in 10 and 30 s test conducted on men and women was observed by Jacobs et al. [19]. Also, Mero [29] in his research on training and non-training boys who performed 15 and 60 s tests on the cycloergometer did not find differences in the maximal LA concentration between groups though their anaerobic capacity differed significantly.

The literature contains a small number of papers describing the effect of pedalling rate on post-training power changes. Consequently the question arises how training composed of maximal intermittent efforts and performed in different rhythms on the cycloergometer influences the maximal power and anaerobic capacity.

The aim of this work was to determine the influence of maximal effort training varying in pedalling rate on the anaerobic capacity, post-exercise maximal concentration of LA and the acid-alkali balance changes in the capillary blood. Identification of the dependence between lactic acid concentration and anaerobic capacity produced in the Wingate test was also the goal. The hypothesis that cycloergometer training consisting of maximal efforts with a load equal to 10% of body weight (BW) will elicit bigger changes of measured values in comparison to training performed with a load of 5% BW was verified.

## MATERIALS AND METHODS

Twenty non-athletes, students of University of Physical Education in Warsaw (UPE), took part in the study. They were divided into 2 groups. The first group (M10; n=9) performed maximal efforts with a load equal to 10% of body weight (BW). The second group (M5; n=11) performed maximal efforts with a load of 5% BW. Examined subjects' characteristics are presented in Table 1. Considering anthropometric traits, the groups did not differ significantly.

The Scientific Research Board of Ethics accepted this research. Students were informed about the study goal and methodology. They also acknowledged the possibility of resignation at every stage of the experiment. Subjects accepted the above conditions in writing.

All training and measurements were conducted in the morning. *Experiment.* Examined subjects read the research protocol and performed the Wingate test (7.5% of body weight loaded) on the cycloergometer (Monark 824E Sweden) according to the standard

methodology described in the work of Inbar et al. [17] before the experiment started.

All groups performed training for one month 4 times a week. They used the Monark 824E (Sweden) cycloergometer linked with a computer (MCE v. 4.0 software; JBA, Zb. Staniak, Poland). Subjects conducted the test and training in a sitting position, not standing on pedals, and beginning motionless. Feet were fastened to pedals with straps. Students were encouraged to reach the maximal speed as fast as they could and maintain it until the end of the test. Measurements and calculations of the maximal power, amount of performed work as well as the work and rest periods were obtained using the MCE software. A single training session encompassed:

- Group M10 – 5 maximal efforts: in the first they performed 100% of work determined earlier in the Wingate test ( $19.36 \pm 2.58$  kJ), and in the other 4 tests, 50% of the above work (10% of body weight loaded). Efforts were separated by 2-min intervals.
- Group M5 – 5 maximal efforts: in the first they performed 100% of work determined earlier in the Wingate test ( $19.16 \pm 2.30$  kJ), and in the other 4 tests, 50% of the above work (5% of body weight loaded). Efforts were separated by 2-min intervals.

The purpose of such a load put on the cycloergometer scale was to gain various external resistances directly influencing the pedalling rate during maximal effort. The load of 10% BW elicited a lower average pedalling rate in comparison to 5% BW load. As the amount of performed training work was the same in both groups the intensity of practice ought to be differentiated.

Examined subjects did not perform additional exercises and had no food supplementation throughout the experiment.

Control measurements of anaerobic capacity (Wingate test) were taken every Monday: before the test (0), during 4 weeks of training (1-4) and for 2 weeks after the test (5-6). Blood for the determination of lactic acid concentration and acid-alkali balance was taken from the fingertip before the Wingate test – in the 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup> and 30<sup>th</sup> resting minute. Measurements were done on Monday before the experiment (0), after two (2) and four weeks of training (4), as well two weeks after the test (6). The lactic acid concentration was additionally measured in both groups before the 16<sup>th</sup> training session and after it. *Anaerobic capacity measurement.* The Wingate test was performed after the standard warm-up on the cycloergometer and 5-min resting interval. The test consisted of 30 s maximal effort with individually adjusted load (body mass considered) [3,17]. The load equalled 7.5% of body weight. The cycloergometer Monark 824 E (Sweden)

**TABLE 1.** CHARACTERISTICS OF EXAMINED GROUPS (MEAN  $\pm$  SD)

Group	Age [years]	Body height [cm]	Body mass [kg]
M10 (n = 9)	22.2 $\pm$ 1.8	178.1 $\pm$ 6.5	77.8 $\pm$ 10.5
M5 (n = 11)	22.5 $\pm$ 0.9	180.7 $\pm$ 7.6	78.0 $\pm$ 11.1

Note: Training consisting of maximal efforts with load equal to: 10% BW – group M10; 5% BW – group M5.

linked to an IBM PC Pentium (MCE v. 4.0 software; JBA, Zb. Staniak, Poland) was used in tests. Gauges were put on the flywheel, which made a distance of 6 m during one pedalling circle. Subjects fixed their saddle and steering wheel and performed the test beginning motionless and not standing on the pedals. Feet were fastened to the pedals with straps. Subjects were encouraged to reach the maximal speed as fast as they could and maintain it until the end of the test. Measurements and calculations of maximal power ( $P_{max}$ ), mean power ( $P_m$ ), work performed in 30 s effort ( $W$ ) and fatigue index (FI) were obtained using the MCE v.4.0 software.  $P_m$  was calculated as the quotient of work performed in the test and duration of effort. FI was calculated as the ratio of the average power decrease from  $P_{max}$  and the power value at the end of the test. Changes of power in time were calculated as the average power in the following 3 s test partitions. Additionally, the 30 s power run was divided into two sections lasting for 10 s ( $P_{m10}$ ) and 20 s ( $P_{m20}$ ). *Methods of lactic acid and acid-alkali balance determination.* The capillary blood was taken from the fingertip and placed in heparinized tubes for lactic acid concentration and acid-alkali balance determination. Blood was taken before performing the Wingate test and in the 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup> and 30<sup>th</sup> minute of the rest.

The lactic acid was analysed using prepared kits for lactic acid determination, Lactat Enzymat DRLANGE of Dr B.Lange GmbH (Germany), in a mini-photometer, LP 20 of DRLANGE Company (Germany).

The following parameters of the acid-alkali balance were analysed in the blood gas analyser Ciba-Corning 284 (UK): BE,  $HCO_{3ACT}$ ,  $pCO_2$  and pH. In the post-exercise analysis of acid-alkali balance parameters only pH was compiled as considering parallel run of other indices. Results of the Wingate test, lactic acid concentration and acid-alkali balance were compared with the ANOVA/MANOVA analysis of repeated measurements. The significance of difference between means was examined post hoc with the least significant difference (LSD) test. The degree of dependence between the anaerobic capacity indices and the lactic acid concentration was evaluated based on Pearson's correlation coefficients. All calculations were done using Statistica™ v.5.5 software (StatSoft, Inc., USA).

**RESULTS**

The results are presented in Table 2. Changes of maximal power ( $P_{max}$ ) were insignificant in both groups. Significant differences were observed between the groups after the second week of rest.

In the case of mean power ( $P_m$ ) the most important changes were noted in the first week from training (M10 – 6.5%; M5 – 11.0%). No significant differences were found between groups (Fig. 1).

The fatigue index (FI) decreased significantly in M10 from 20.3±4.7 to 15.1±6.1% after 2 weeks of rest. The most significant changes of FI were found in group M5 after 4 weeks of training.

The analysis of the average power route in the first 10 s ( $P_{m10}$ ) and the remaining 20 s ( $P_{m20}$ ) of the Wingate test in group M10

**TABLE 2.** AVERAGE VALUES (±SD) OF: THE MAXIMAL ( $P_{max}$ ) AND MEAN ( $P_m$ ) POWER, FATIGUE INDEX (FI) AND THE SIGNIFICANCE OF DIFFERENCES BETWEEN AVERAGES IN THE MEASUREMENT TAKEN BEFORE TESTS (0) AND SUBSEQUENT MEASUREMENTS: (1-4) – 4 WEEKS TRAINING, (5-6) – 2 WEEKS AFTER TRAINING PERIOD (\*-  $p < 0.05$ ).

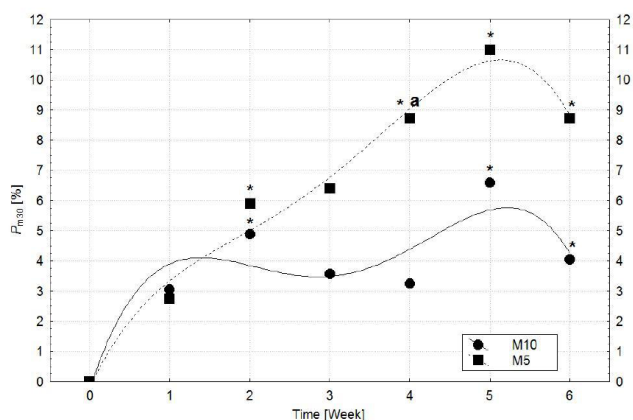
Variables		0	1	2	3	4	5	6
$P_{max}$ [W]	M10	826.9±122.0	822.5±79.5	835.5±96.2	797.3±111.1	804.2±107.4	835.6±101.5	802.6±115.0°
	M5	832.7±117.4	795.2±113.8*	845.6±113.6	811.7±108.1	824.1±99.7	860.6±101.6	853.8±117.7
$P_{max}/mass$ [W/kg]	M10	10.61±0.68	10.63±0.79	10.73±0.78	10.28±1.05	10.34±0.90	10.74±0.69	10.31±0.89°
	M5	10.80 ±10.61	10.23±10.63*	10.87±10.73	10.45±10.28	10.59±10.34	11.07±10.74#	10.96±10.31 <sup>ao</sup>
$P_m$ [W]	M10	645.3±85.7	661.2±61.7	673.8±65.6*	665.1±71.4	665.8±91.1	686.1±78.7*	669.2±75.0
	M5	633.6±87.9	648.5±90.9	668.1±85.0*	671.5±86.5*	687.0±91.8*	700.0±86.1*	687.4±95.9*
$P_m/mass$ [W/kg]	M10	8.31±0.59	8.54±0.57	8.71±0.60*	8.59±0.69	8.57±0.72	8.85±0.57*	8.64±0.74*
	M5	8.14±0.58	8.33±0.46	8.60±0.54*	8.64±0.46*	8.83±0.48*	9.01±0.51*	8.83±0.46*
FI [%]	M10	20.3±4.7	18.9±5.2	18.7±4.6	15.7±5.6*	16.6±4.1*	16.4±4.0*	15.1±6.1*
	M5	22.1±5.5	18.1±3.9*	20.3±3.2	16.6±3.7*	16.0±4.4*	17.6±4.5*	19.5±4.8 <sup>a</sup>

Note: Training consisting of maximal efforts with load equal to: 10% BW – group M10, 5% BW – group M5; # – averages differ significantly between 4th, 5th and 6th recording, ° – averages differ significantly between 5th and 6th measurement, M10 vs. M5, a –  $p < 0.05$ ;

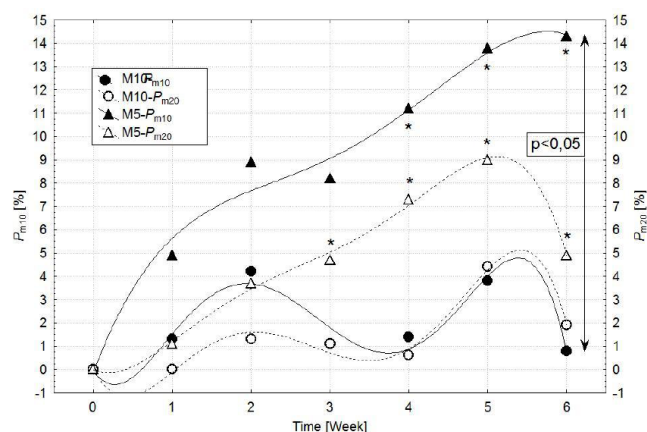
**TABLE 3.** AVERAGE VALUES (±SD) OF THE MEAN POWER PRODUCED IN THE FIRST 10 s ( $P_{m10}$ ) AND REMAINING 20 s ( $P_{m20}$ ) OF THE WINGATE TEST AS WELL AS THE SIGNIFICANCE OF DIFFERENCES BETWEEN AVERAGES MEASURED BEFORE THE EXPERIMENT (0) AND SUBSEQUENTLY: (1-4) – 4 WEEKS OF TRAINING, (5-6) – 2 WEEKS AFTER TRAINING PERIOD (\*-  $p < 0.05$ ).

Variables		0	1	2	3	4	5	6
$P_{m10}$ [W]	M10	688.4±112.4	689.2±78.9	708.8±81.1	690.2±96.5	693.0±99.1	707.2±87.0	686.9±91.0
	M5	657.3±148.2	668.6±107.2	696.1±111.6	691.9±102.0	705.9±107.8	724.8±93.0*	735.7±118.6*
$P_{m20}$ [W]	M10	650.6±101.0	645.1±68.8	652.9±64.6	651.8±65.6	650.8±90.6	674.4±79.6	658.0±74.0
	M5	628.6±59.9	636.4±86.	651.8±75.9	658.5±81.1*	674.8±88.0*	685.8±86.8*	660.9±89.9*

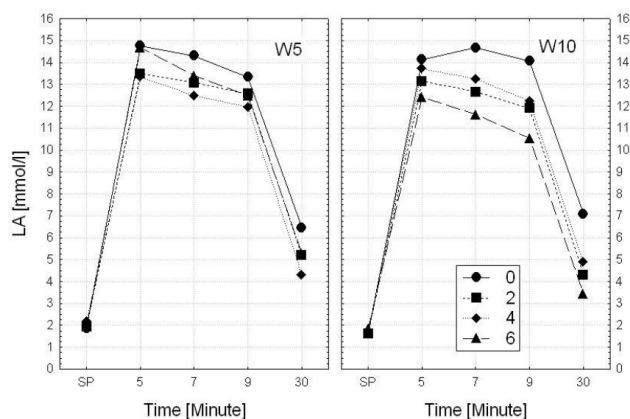
Note: Training consisting of maximal efforts with load equal to: 10% BW – group M10, 5% BW – group M5.



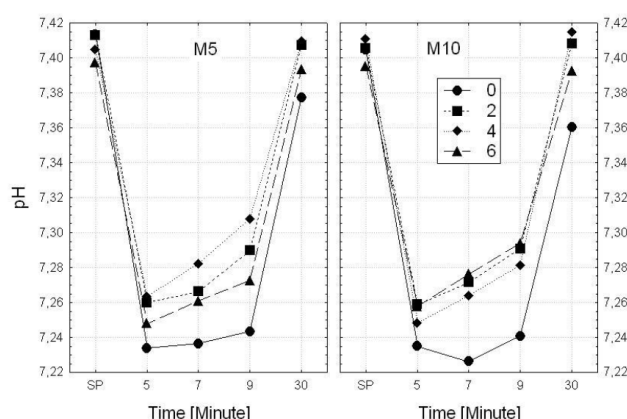
**FIG. 1.** AVERAGE VALUES (%) OF THE MEAN POWER CHANGES ( $P_m$ ) PRODUCED IN THE WINGATE TEST CALCULATED ACCORDING TO THE MEASUREMENT TAKEN BEFORE EXERCISES AND THE SIGNIFICANCE OF DIFFERENCES BETWEEN AVERAGE MEASUREMENTS TAKEN BEFORE THE EXPERIMENT (0) AND SUBSEQUENTLY: (1-4) – 4 WEEKS OF TRAINING, (5-6) – 2 WEEKS OF REST (\* -  $p < 0.05$ ); M10 VS. M5, <sup>a</sup> -  $p < 0.05$



**FIG. 2.** AVERAGE VALUES (%) OF THE MEAN POWER CHANGES IN THE FIRST 10 ( $P_{m10}$ ) AND NEXT 20 S ( $P_{m20}$ ) OF THE WINGATE TEST CALCULATED IN RELATION TO THE MEASUREMENT TAKEN BEFORE THE EXPERIMENT AND THE SIGNIFICANCE OF AVERAGE DIFFERENCES MEASURED BEFORE TESTS (0) AND SUBSEQUENTLY: (1-4) – 4 WEEKS TRAINING, (5-6) – 2 WEEKS POST-EXERCISE PERIOD (\* -  $p < 0.05$ ).



**FIG. 3.** CHANGE OF LACTIC ACID (LA) CONCENTRATION AFTER THE WINGATE TEST IN GROUPS M10 AND M5; (MEASUREMENT TAKEN BEFORE THE STUDY (0), AFTER TWO (2), FOUR (4) WEEKS OF TRAINING AND TWO WEEKS AFTER THE RESEARCH (6), SP – RESTING VALUE).

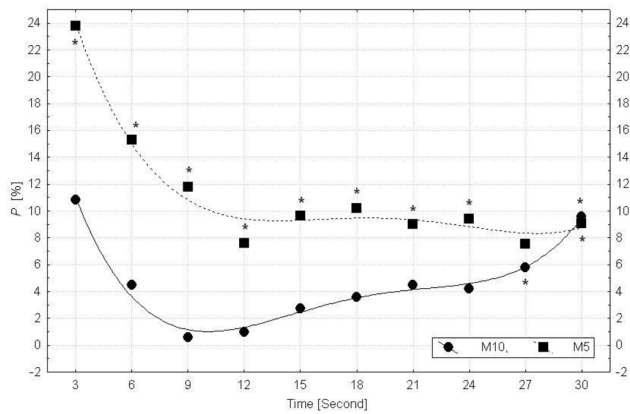


**FIG. 4.** CHANGE OF PH CONCENTRATION AFTER THE WINGATE TEST IN GROUPS M10 AND M5 (MEASUREMENT PERFORMED BEFORE THE EXPERIMENT (0), AFTER TWO (2), FOUR (4) WEEKS OF TRAINING AND TWO WEEKS AFTER TESTS (6), SP – RESTING VALUE).

showed no significant changes of  $P_{m10}$  in the first week after training in both absolute values (Table 3) and percentage differences calculated according to measurements conducted before the study (Fig. 2). Significant differences of  $P_{m10}$  were observed in group M5 in the first and second of the resting period.  $P_{m20}$  changed significantly in this group after 3 and 4 weeks of training and in both control weeks after the test. The percentage changes calculated according to recordings taken before the study were significant after 4 weeks of exercise and two weeks after the test period. Group M5 displayed bigger post-training changes for  $P_{m10}$  than for  $P_{m20}$ . Mean values of the percentage  $P_{m10}$  changes differed significantly between groups 2 weeks after the experiment.

The lactic acid (LA) concentration in the capillary blood measured before the 16<sup>th</sup> training session and after it amounted to  $17.52 \pm 3.73$  mmol/l in M10 and  $19.15 \pm 2.21$  mmol/l in M5. No significant differences in LA concentration were found between groups.

The analysis of lactate concentration after the Wingate test showed its highest value displacement in time from the 7<sup>th</sup> minute in the measurement taken before the test to the 5<sup>th</sup> minute in other control measurements (Fig. 3) in group M10. The highest significant changes of the LA concentration were noted in measurements taken 2 weeks after the experiment in the 5<sup>th</sup>, 7<sup>th</sup> and 9<sup>th</sup> minute. In group M5 all the control measurements presented the highest LA concentration in the 5<sup>th</sup> minute from Wingate test completion. The biggest changes calculated according to measurements conducted before tests were observed after 4 weeks of training in the 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup> and 30<sup>th</sup> minute. The highest LA concentration (5<sup>th</sup> min) detected after the 2-week resting period was close to the value obtained before the test. Average values of the individual LA concentration peak (the highest LA concentration in the Wingate test for each examined subject) changed significantly in group M10 from  $15.233 \pm 2.367$  mmol/l before the tests to  $12.340 \pm 2.353$  mmol/l in the recording taken 2 weeks after the experiment. Group M5



**FIG. 5.** AVERAGE VALUES (%) OF POWER ( $P$ ) CHANGES ANALYSED IN 3 S INTERVALS, PRODUCED IN THE WINGATE TEST PERFORMED IN THE FIRST WEEK AFTER PRACTICE (5), CALCULATED ACCORDING TO THE MEASUREMENT PRECEDING THE EXPERIMENT (0) – PRESENTED IN PERCENTAGES AND THE SIGNIFICANCE OF DIFFERENCES BETWEEN CONSECUTIVE MEASUREMENTS: (0) – BEFORE TESTS, (5) – FIRST WEEK OF THE POST-TRAINING PERIOD (\* -  $p < 0.05$ ).

differed significantly as regards LA peak observed before the test ( $15.109 \pm 1.739$  mmol/l) and LA peak noted after 4 weeks of training ( $13.491 \pm 2.098$  mmol/l).

A similar displacement in time was noted in the case of the pH concentration (from 7<sup>th</sup> to 5<sup>th</sup> min) in group M10 (Fig. 4). Significant differences between the measurement conducted before the experiment and subsequent ones occurred after 4 weeks of training and after the 2-week resting period in the 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup> and 30<sup>th</sup> minute. A significant decrease of the resting pH in the measurement taken 2 weeks after the test was noted additionally in both groups.

## DISCUSSION

The main finding of the presented work was that the training consisting of maximal efforts (Wingate test) elicited, in both groups, a decrease of the lactic acid concentration after 4 weeks of training in comparison to LA values obtained before the experiment. The growth of the mean power by 6.6% in group M10 and 11.0% in M5 accompanied the decrease of LA. The results are only partly consistent with other authors' outcomes. In the studies of Linossier et al. [22,23], Pary et al. [33], Sharp et al. [39] and Simoneau et al. [41] "sprint" training caused an increase of the maximal and average power as well as increased activity of glycolytic enzymes. In the studies of Esbjörnsson Liljedahl et al. [11], Jacobs et al. [20], MacDoughall et al. [25] and Rodas et al. [37] the above increased activity was not accompanied by maximal power increase. However, in the work of Simoneau et al. [40] a power increase occurred in 10 and 90 s efforts in spite of the lack of increased activity of glycolytic enzymes. This was in opposition to the results attained by the same authors [41], where similar training elicited increases of the above enzyme activity and power in 10 and 90 s maximal efforts on the cycloergometer. Also the influence of training consisting of 30 s efforts with high intensity on power changes measured in the Wingate test is not unambiguous. In the works of Jacobs et al. [20] and Rodas et al. [37] a significant increase of maximal and mean power in

the Wingate test conducted after the training and consisting of 15 and 30 s maximal efforts was not found. The study of Parry et al. [33] examined subjects who performed similar training on the cycloergometer consisting of 15 and 30 s maximal efforts. They also were divided into 2 groups. The power peak and the mean power in 30 s Wingate test increased significantly in the group training every third day by 20 and 14% respectively while in the group training each day changes were insignificant (3% for both indices). Results differ significantly between groups. In the works of Allemeier et al. [1], MacDoughall et al. [25] and McKenny et al. [27] where training involved 30 s maximal efforts no significant changes of maximal ( $P_{max}$ ) or average ( $P_m$ ) power were noted in the Wingate test. Nevertheless, in the study of O'Connor [32] a non-significant increase of the maximal power by 7.1% and a significant increase of the mean power by 19.5% were observed. Esbjörnsson Liljedahl et al. [11] reported non-significant post-training maximal and mean power changes (1.4% and 1.4% respectively) measured in the Wingate test in the group of male subjects. Considering women, these values increased respectively by 6% and 10.6%. In the work of Stathis et al. [42] an increase of the maximal (16.8%) and average (11.8%) power was noted in the Wingate test after 7 weeks of training involving 30 s maximal efforts. In this work, sprint training on the cycloergometer elicited non-significant changes of the maximal power by 1.5% in the M10 group and 3.9% in M5. Changes of the mean power were significant in both groups and were 6.6% and 11.0% respectively. Obtained changes of the maximal power (expressed as percentages) are consistent with those obtained by Allemeier et al. [1], Esbjörnsson Liljedahl et al. [11], Jacobs et al. [20], McKenny et al. [27] and Rodas et al. [37]. The lack of significant changes of maximal power in groups M5 and M10, as in the study of Parry et al. [33], could be the effect of 4 weeks' daily training. Studies where training lasted from 6 to 8 weeks [22,33,39] evoked a significant increase of the maximal power. In contrast to papers reporting insignificant changes of the maximal and mean power [1,11,20,27,37], our research detected significant growth of the latter. Training in group M10 with a load close to the optimal (the highest power produced during the  $F-v$  and  $P-v$  characteristics determination) turned out to be ineffective for the  $P_{max}$  increase in the Wingate test. However, for anaerobic capacity (measured as the average power) more effective was the training performed by group M5. If we accept that the maximal effort training done with a 5% BW load (group M5) occurs within the 30-80% maximal load range, then the similar power increases obtained in this research are consistent with the results of Moss et al. [31], who did not find significant differences in the maximal power produced after 9 weeks of strength training performed with maximal speed and load (35 and 95%). This thesis is supported by the results of Moritani et al. [30] and Wilson et al. [44], who reported that exercises performed with a load equal to 30-40% of the maximal load develop power and fitness in the best possible way.

Analysing the post-training changes of power in 30 s efforts separated by 2 s intervals Linossier et al. [22] found that 7-week training consisting of 5 s maximal efforts caused a significant change of power in the Wingate test (until the 18<sup>th</sup> second in comparison to results from before the experiment). In the study of Stathis et al. [42] the power course calculated in 5 s sections changed significantly during the first 25 s of the test performed after the 7 weeks of training consisting of 30 s maximal efforts (the biggest changes during the first 10 s). Esbjörnsson Liljedahl et al. [11] reported that the power routes calculated in the 5 s gulfs were displaced parallelly to each other before and after the training involving 30 s efforts in both male and female groups. Comparison of the percentage changes of power analysed in 3 s compartments in our research (Fig. 5) showed that a significant change of power in group M10 occurred in the last 6 s of the test. In group M5 significant changes were seen in all the 30 s power course. Analysis of the power recorded during the first 10 s ( $P_{m10}$ ) and the remaining 20 s ( $P_{m20}$ ) of the test showed that both forms of training used in this work improved  $P_{m10}$  by 3.8% in group M10 and 14.3% in M5 and  $P_{m20}$  by 4.4% in M10 and 9.0% in M5. These results show that the practice applied in group M5 caused higher changes in the initial phase of the Wingate test in relation to group M10, although differences between groups were not significant.

The energy used during the 30 s Wingate test comes from anaerobic and aerobic sources [3]. According to Bar-Or [3] 13-28%, Calbet et al. [8] 22.9% and Medbø and Tabata [28] 40% of total energy produced during the Wingate test originates from aerobic sources. Provided that the maximal power and time used for its production determine the anaerobic-phosphagen possibilities then the amount of work performed in 30 s effort and/or the average power become basic indices of the anaerobic capacity [3,34,36,46], including the anaerobic-lactic potential [18,47]. Jacobs et al. [24] and Wojcieszak [47] stated that the highest power produced in the Wingate test comes from intra-muscular sources. Since the muscle phosphagen supply is restricted, continuation of further effort is possible through its regeneration in the process of anaerobic glycolysis. The effect of anaerobic glycolysis participation in covering the energetic demand during 30 s effort is the growth of lactic acid concentration in the blood. It is accompanied by changes of the blood acid-alkali balance: pH decrease and alkali deficiency. It is believed that training elicits an increase of the lactic acid transportation from muscles to blood and accelerates its utilisation (elimination) from blood through the liver and muscles. The kind of training (speed, endurance, and strength) [24] and its intensity [26] influence it. MacRae et al. [26] suggested that after low-intensity training lactic acid production is falling and after high-intensity training it is growing. In the work of Philips et al. [35] 10 days' training on the cycloergometer (effort lasting for 2 h, 59%  $Vo_{2max}$ ) elicited growth of the metabolism by lowered LA level. The reduced level of intra-muscular LA suggests according to Philips et al. [35] decrease of the early recruitment of glycolysis in exercise. It is believed that the maximal concentration

increase after training is the result of adaptation to high-intensity training [16,38]. This result is connected with increased activity of phosphofructokinase (PFK) – glycolytic potential enhancement [20,39]. In the research of Houston et al. [16], Jacobs et al. [20], Sharp et al. [39] and Rodas et al. [37] an increase of lactic acid was observed in the Wingate test performed before and after the experiment. In the work of Jacobs et al. [20] the lactic acid concentration measured 4 min after the test increased significantly from  $11.4 \pm 1.0$  to  $12.5 \pm 1.3$  mmol/l (9.7%) after 6-week training consisting of 15 and 30 s maximal efforts on the cycloergometer. In the study of Rodas et al. [37] 14-day cycloergometer training performed with similar maximal efforts elicited significantly higher (by 37.2% in the 5<sup>th</sup> min and 22.7% in the 7<sup>th</sup> min) concentration of LA in comparison to the measurement taken before the research. The peak LA concentration occurred in the 7<sup>th</sup> min of the test before the experiment and after it in minute 5. The LA concentration in the 5<sup>th</sup> and 7<sup>th</sup> min was equal. The intra-muscular LA concentration lowered significantly. In the work of Sharp et al. [39] 8-week training consisting of 30 s efforts caused significantly higher LA production (by 40% in the 3<sup>rd</sup> min) after the 45 s sprint test. The peak of this enzyme production before the test occurred in the 15<sup>th</sup> min while after the training in minutes 3 and 15. Also the intra-muscular LA went up after the training. The growth of lactate accumulation after the sprint training was not accompanied by significant changes of pH in muscles. During this research all groups performed 4-week training consisting of maximal efforts on the cycloergometer. It elicited a decrease of the post-exercise LA concentration occurring in the Wingate test in the 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup> and 30<sup>th</sup> min by -3%, -9.7%, -13% and -31% in M10 respectively and by -9.7%, -12.8%, -10.2% and -33.5% in M5. In group M10 these changes intensified 2 weeks after the experiment by -12.2%, -20.8%, -25.1% and -51.4%. This may imply that the training applied in group M10 caused remote effects considering lactate and acid-alkali balance utilisation. Perhaps this explains the lower increase of mean power in group M10 in comparison to M5. These results are consistent with the results of Parry et al. [33], although in this work produced power differences were caused by the training intensity (various pedalling rates) and in Parry's study [33] by the use of training not separated in the first group and with a 2-day interval in the second. Values of the lactate and pH concentration obtained in this study are not consistent with opinions voiced so far stating that training performed with maximal efforts causes post-exercise LA concentration growth in the Wingate test [16,26,37,39] and training consisting of sub-maximal efforts induces an LA concentration fall [26,35]. The decrease of the LA concentration observed in this research in both groups is in agreement with the results of Lutosławska et al. [24], who noted lowering of LA production in the Wingate test performed by wrestlers after the training period. It was accompanied by significant maximal power growth and insignificant increase of average power. The LA concentration decrease noted in the above works could be the result of glycogen decomposition and lactic acid accumulation lowering in

muscles during performance of the post-training Wingate test. The lactate concentration reduction in blood could also be elicited by the growth of lactate utilisation in muscle fibres [37]. The decrease of energy production in the aerobic pathway could correlate with the increase of produced power usage in the anaerobic way [14]. It should be borne in mind that maximal effort training may elicit an increase in lactic acid use as the metabolic source for the production of power in the aerobic pathway. Use of lactate as the muscle energy source was described in the work of Phillips et al. [35] as a result of the post-training changes. The kinetics of lactate "excretion" from muscles to blood is not fully recognised. Rodas et al. [37] suggest that lactates are removed from muscles to blood through lactic conveyers. This mechanism might be the consequence of the training eliciting bigger or smaller eruption of lactates to the blood and at the same time causing a decrease or increase of the blood LA concentration [6].

It is believed that the dependence between the maximal lactic acid concentration and anaerobic work may be changing towards applied training. Nevertheless, there are only a few works examining this subject in the literature [24]. Significant correlations between lactic acid concentration and anaerobic test results were reported in the papers of Berg and Keul [5], Fujitsuka et al. [13], Granier et al. [14], Linossier et al. [22], Lutostawska et al. [24] and Tamayo et al. [43]. The correlation coefficients were: for  $P_{max}$  vs. LA  $r = 0.87$  [22];  $r = 0.75$  [14]; for  $P_m$  vs. LA  $r = 0.76$  [14];  $r = 0.73$  [15];  $r = 0.799$  and  $r = 0.810$  [24];  $r = 0.47$  [43]. On the other hand, Gratas-Delamarche et al. [15] did not find a significant correlation between the LA concentration and work performed by sprinters in the Wingate test. Jacobs et al. [19] did not find a relationship of the LA concentration and power in 10 and 30 s tests in women and men. In the presented research both groups did not display significant dependence between the maximal and average power and the lactic acid concentration in the capillary blood in the 5<sup>th</sup>, 7<sup>th</sup> and 9<sup>th</sup> minute. In group M10 the highest insignificant relationship of LA and

$P_{max}$  mass was noted after 4 weeks of training ( $r = 0.54$ ,  $r = 0.63$ ,  $r = 0.43$  respectively). A significant association of LA and  $P_m$  mass was also not found. Significant dependencies of  $P_m$  mass and LA were found in group M5 after 2 weeks of training – 5<sup>th</sup>, 7<sup>th</sup> and 9<sup>th</sup> minute ( $r = 0.64$ ;  $r = 0.56$  and  $r = 0.63$  respectively). A significant dependence between  $P_{max}$  mass and LA was noted in all control measurements conducted in the 7<sup>th</sup> and 9<sup>th</sup> minute. The correlation coefficient values were within the range 0.68-0.90. Based on the obtained results it seems as if the linear dependence of the LA concentration and amounts measured in the Wingate test were incidental.

Discrepancies existing in the literature and considering post-exercise LA concentrations might be due to different times of taking blood samples after the Wingate test. There are studies in which the blood taking was conducted after the first [4], second [2], third [7,24], fourth [20], fifth [37], eighth [45], ninth [12] and tenth [21] min. In this research blood taking was conducted before the test and in the 5<sup>th</sup>, 7<sup>th</sup>, 9<sup>th</sup> and 30<sup>th</sup> min. This allowed observation of the LA production peak time shift in group M10. A similar effect of earlier LA peak concentration occurrence was noted in the studies of Rodas et al. [37] and Sharp et al. [39], who described the shortening of the highest LA ejection after maximal effort training.

## CONCLUSIONS

In conclusion, both forms of training elicited similar maximal power growth produced in the Wingate test. Maximal effort training with a load equal to 5% of body weight caused higher growth of the average power compared to training with a load of 10% BW. The lack of significant changes between groups indicates that the pedalling rate does not significantly influence the anaerobic capacity. A surprising observation was the lowering of lactic acid concentration in the Wingate test performed after 4 weeks of training in comparison to the LA values obtained in measurements before the experiment. It seems that the linear relationship between lactic acid concentration and results of the Wingate test might have a circumstantial character.

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