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ECONOMICAL AND OPTIMAL PEDALLING VELOCITY CHARACTERISTICS DURING MAXIMAL AND SUBMAXIMAL EFFORTS ON CYCLOERGOMETER

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Abstract. This investigation was undertaken in order to verify the hypothesis that there exist some relationship between the optimal and economical pedalling rate in maximal efforts and the economical pedalling speed in submaximal efforts. The 3-min efforts with the space of 7 days between them were performed fourfold on the cycle ergometer (Monark E 824 joined with the computer) by examined subjects during the submaximal efforts test. The effort power amounted to 250 W and mechanical work quantity to 45 kJ. The pedalling speed grew in respective trials in following manner: 40, 60, 80 and 100 rpm. The economical pedalling rate (v_e) was defined as such a pedalling which enabled the least oxygen intake by applied load. The cycle ergometer Wingate test with the load equal 7.5% of body weight (BW) was performed during the maximal test by every examined subject. Next, after the interval of at least 3 days they performed 4 trials with the respective loads: 2.5%; 5%; 10% and 12.5% BW according to the Wingate test formula. The end of trial was obtained when the results of work were equal with the 7.5% BW Wingate test ones. Results obtained in the maximal efforts allowed calculation of the force-velocity (*F-v*) and power-velocity (*P-v*) dependencies for every experiment participant in purpose of the individual maximal power (P_{max}) and optimal speed (v_o - pedalling rate by which P_{max} occurred) determination. The gas analyser (SensorMedics Co.) was used in order to oxygen intake markings. Average values (±SD) of the net mechanical efficiency (NE) in submaximal efforts for pedalling rates of 40, 60, 80 and 100 rpm amounted respectively: 23.0±1.8; 22.9±2.1; 23.5±2.2 and 19.6±2.8%. Average value of the economical pedalling rate calculated for VO_2 net equalled: $v_{eVO2net}$=62.5±21.8 rpm and oxygen usage of VO_{2min}=31.56±2.90 $ml \cdot mn^{-1}$ while NE v_{eNE} equalled 62.5±14.8 rpm with average NE=23.9±2.5%. Mean values (±SD) of net mechanical capacity in maximal efforts amounted respectively: 12.5±1.5; 17.3±2.3; 18.2±3.2; 19.9±4.7 and 19.1±2.4%. The average maximal power value (P_{max}) calculated from the individual dependencies amounted to 1031.6±115.5 W (13.10±1.90 W/kg) by mean optimal frequency v_o=109.2±12.0 rpm. Some significant dependencies between optimal

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pedalling frequency and economical pedalling rate in maximal and submaximal efforts were found namely: negative for the economical pedalling speed calculated from net VO_2 (r=-0.51; R^2=0.264) and positive for the economical pedalling rate counted from the net mechanical efficiency (r=0.95; R^2=0.907). The significant dependency between the economical pedalling speed obtained during the maximal effort and economical pedalling frequency calculated for the submaximal effort (r=0.788; R^2=0.622) was stated.

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Key words: Cycle ergometer - Economical and optimal velocity - Force-velocity characteristic - Mechanical efficiency - Power output

Introduction

The mechanical muscles characteristics are usually determined during the maximal or submaximal efforts. In maximal efforts the power is measured on the non-isokinetic cycle ergometer such as Monark E 824 type [7,26,43] or isokinetic one [4,31,34]. The maximal power is determined most frequently from the force-velocity (*F*-*v*) and power-velocity (*P*-*v*) dependence [15,27,31,34,43,46]. In the in vitro research the maximal power was produced by the optimal velocity and power and the force-velocity dependence (*F*-*v*) was described as hyperbole [23]. In the in vitro studies conducted during the cycle ergometer exercises engaging the whole muscles group the *F*-*v* dependence track according to Hill's equation [46] or linear [15,31,43] was seen and the optimal speed (v_o) was defined as a pedalling rate by which the maximal power (P_{max}) occurred [28,29,43]. It is commonly acknowledged that the muscle fibres proportion have an influence on the maximal power production by optimal rate - the more FT fibres the bigger produced power by higher optimal speed is [23,31]. In the work of Hautier *et al.* [22] the relationship of FT fibres amount and optimal pedalling rate was found (r=0.88).

The "optimal/economical pedalling rate" expression is defined in submaximal efforts as the pedalling rate by which examined subject use the least amount of oxygen by applied load. The economical pedalling speed was marked in references within the range of 60 to 100 rpm [10,21,32,40]. Few papers presented that the economical value of pedalling grows along with the performed on the cycle ergometer effort power [5,10,36]. In the study of Marsh and Martin [30] the economical pedalling frequency amounted in all efforts (75, 100, 150, 200 W) 50 rpm. The same oxygen intake was observed in 200 W effort by 50 and 65 rpm. A few works results show that the gross efficiency grows also with the load increase

[10,19,36]. Additionally, in studies [10,11,32] the gross mechanical efficiency was growing while the pedalling rate was increasing from 40 to 60 rpm [10,11] and next was changing by the rate of 80 rpm and presented similarity with 100 rpm result. In case of the submaximal efforts there was stated that subjects characterised by FT muscles fibres predominance displayed bigger economical pedalling rate in relation to participants with ST muscles fibres prevalence [13,36,38]. The significant relationship between the gross mechanical efficiency (GE) and the percentage composition of ST fibres (r=0.75) was found by Cole *et al*. [14]. These results suggest that the muscles fibres composition also influences the economical pedalling rate [13,38].

Basing on references it seems that muscles fibres proportion may influence the optimal and economical pedalling speed in maximal and submaximal efforts and that such a pedalling rates depend on the same mechanical and physiological muscles properties. There was only one paper [24] found in references which measured the relationship of optimal and economical pedalling rate in maximal and submaximal efforts.

The aim of this work was the verification of hypothesis that there exist some relationship between the optimal and economical pedalling rate in maximal efforts and the economical pedalling speed in submaximal efforts.

Materials and Methods

Non-training students of APE in number of 8 took part in the research. Examined characteristics: age – 21.6±0.7; body height – 181.4±6.5 cm; body weight – 79.3±7.0 kg.

The study was accepted by the Scientific Research Board of Ethics. All the participants were informed about the experiment aim and its methodology as well as about the possibility of resignation at every stage of the study. Students accepted the above conditions in written.

Experiment: Before the experiment subjects acknowledged the examination procedure.

During the maximal effort test (MA) they performed 5 maximal efforts with the same amount of work. The first was the 30 s Wingate test with the load of 7.5% body weight (BW) put on the cycle ergometer scale. The amount of work produced in this test was accepted as a matrix for the other trials results. Each subject performed, in the interval of at least 3 days, respective trials consisting of maximal efforts on the cycle ergometer with loads equal: 2.5%; 5.0%; 10.0% and 12.5 % BW until the exemplary Wingate test work was obtained. All the trials were made on the Monark 824 E (Sweden) cycle ergometer joined with the IBM PC Pentium with the “MCE v. 4.0” software (“JBA” Zb. Staniak, Poland). Detectors were put on the fly-wheel making a distance of 6 m during one circle. Subjects set their position, wheel and saddle and next performed the test sitting without standing on pedals. They started motionless and with feet fastened to pedals by straps. Examined students were spurred eagerly to obtaining the maximal speed in as short time as they could and keeping it until the end of the test. The “MCE v. 4.0” programme was used as for the following measurements and calculations: mechanical work amount (W_m); effort time (t); mean power (P_m); the highest produced by applied load power (P_n - where n is a load value); velocity (v_n) by which the P_n was obtained and fatigue index (FI) being a difference between P_n and the least value of power reached in the end of a trial divided by P_n.

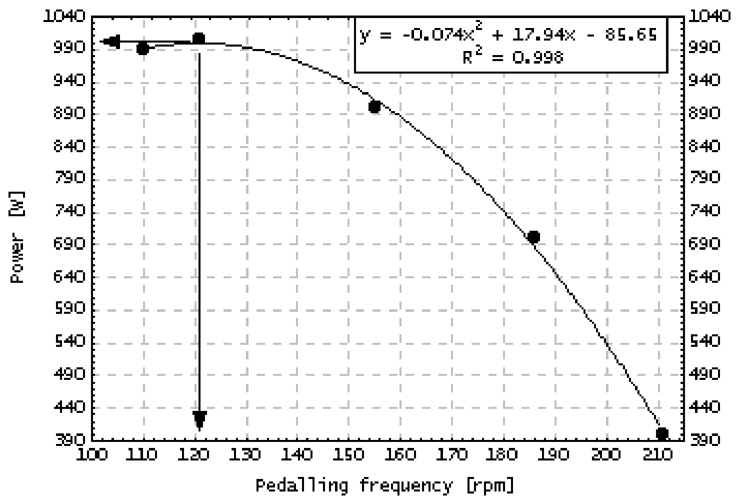

Fig. 1
Exemplary power-pedalling rate dependence obtained in cycle ergometer maximal efforts by an individual subject. Arrows show the maximal power (P_{max}) and optimal pedalling speed (v_o)

Results obtained by each examined in maximal efforts were used for the determination of force-velocity (F-v) and power-velocity (P-v) dependence in order to the individual maximal power capacity (P_o) and optimal speed (v_o - pedalling rate by which P_{max} was produced) marking. The maximal power and optimal velocity were calculated from the individual second degree polynomial equation describing the *P-v* dependence [24,28,29]. The highest point at the curve was defined as a maximal power and responding to it speed as optimal one (Fig. 1).

The 3 min efforts with the space of 7 days between them were performed fourfold by examined subjects on the cycle ergometer (Monark E 824 - Sweden - joined with the IBM PC Pentium with “MCE v. 4.0” software - “JBA” Zb. Staniak, Poland) during the submaximal efforts test. The effort power equalled 250 W and the amount of performed mechanical work - 45 kJ. The pedalling speed in following efforts amounted to: 40, 60, 80 and 100 rpm. Subjects set their position, wheel and saddle and next performed the test sitting without standing on pedals. The subjects task was to keep the constant pedalling speed throughout the test. The “MCE” v. 4.0“ programme was used for the following measurements and calculations: mechanical work amount (W_m); effort time (t) and average power (P_m).

The SensorMedics (USA) gas analyser with the 2900/2900c Metabolic Measurements Cart/System software was used as for the determination of the oxygen intake during all trials on the cycle ergometer and in the resting phase (till the V_E goes back to the resting value). The ventilation and gas variables change were monitored breath by breath and averaged every 20 s in the open ventilation system. Before every examination the gas analyser was calibrated with: O_2 and CO_2 (AGA Gas BV, Holland) gases of known concentration.

The gross mechanical capacity (GE) was counted as the mechanical work and total energy ratio and the net mechanical efficiency (NE) as the mechanical work and net total energy ratio (total energy value diminished by the resting energy value).

According to earlier researches of Coast and Welch [10], Gaesser and Brooks [19], Hintzy *et al*. [24], Marsh and Martin [30] and Seabury *et al*. [36] the economical pedalling rate (v_o) for the submaximal effort was calculated from the individual second degree polynomial equations describing the pedalling rate - VO_{2net} dependence. The lowest point on curve was defined as the most economical pedalling speed (Fig. 2). The average net oxygen intake in the 3rd effort min was used for the marking of VO_{2net}-pedalling frequency dependence.

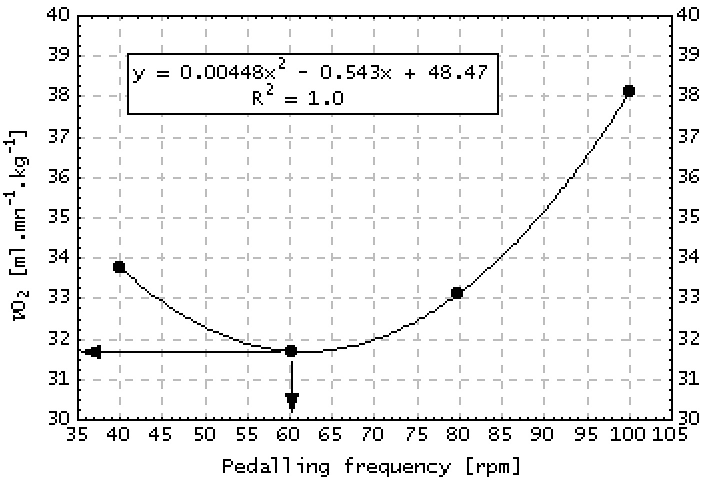

Fig. 2
Exemplary VO_{2net}-pedalling frequency dependence fetched in submaximal cycle ergometer exercises for one examined. Arrows determine the economical oxygen intake for 250 W effort

All measurements were made in the morning.

The MANOVA analysis of variance was used with the purpose of data verification. The significance of differences between averages was compared post hoc with the Tukey's test. The dimension of dependence between amounts was evaluated on the basis of Pearson's correlation coefficients. All the calculations were done using the STATISTICA ™ programme (v 5.5 StatSoft, USA).

Results

The maximal efforts (MA) results are presented in Table 1. The power values differ among respective trials except the values reached by load of 10.0% and 12.5% BW. Average values of the gross and net mechanical capacity attained by load equal 2.5% BW differed significantly in relation to values gained by loads of: 7.5%; 10.0% and 12.5% BW. Mean values of the mechanical efficiency accomplished in trials with load of: 5%; 7.5%; 10%; 12.5% BW did not differ crucially.

Table 1
Average values (±SD) of measured in maximal efforts quantities: v_m-mean velocity; v_n-velocity by which the highest power occurred in respective trials, W_m-mechanical work; P_m mean power; P_n - the highest power in a given trial; FI - fatigue index; E_c - gross total energy; E_{cnet} - net total energy; GE - gross mechanical efficiency; NE - net mechanical capacity; t - effort time

(Quantities)	(Load)				
	2.5% BW	5.0% BW	7.5% BW	10.0% BW	12.5% BW
v_m [obr/min]	154.4	144.7	113.8 [ab]	99.1 [abc]	80.2 [abcd]
	±9.6	±6.6	±5.4	±9.4	±8.2
v_n [obr/min]	195.2	174.3 [a]	142.4 [ab]	121.8 [abc]	96.9 [abcd]
	±13.3	±8.3	±6.4	±10.3	±9.5
W_m [kJ]	19.7	19.8	19.7	19.7	19.7
	±1.8	±1.7	±1.8	±1.8	±1.8
P_n [W]	379.3	676.8 [a]	822.6 [ab]	947.2 [abc]	920.4 [ab]
	±34.9	±52.1	±63.1	±113.9	±101.2
P_n/BW [W/kg]	4.79	8.55 [a]	10.39 [ab]	11.95 [abc]	11.89 [abc]
	±0.33	±0.41	±0.50	±1.01	±1.16
P_m [W]	292.1	546.6 [a]	657.5 [ab]	748.6 [ab]	755.8 [abc]
	±32.7	±48.9	±60.3	±93.2	±81.7
E_c [kJ]	337.0	278.0	268.6 [a]	256.7 [a]	243.6 [a]
	±47.1	±34.2	±44.1	±34.2	±41.4
E_{cnet} [kJ]	159.8	117.2 [a]	112.7 [a]	104.4 [a]	104.9 [a]
	±21.9	±22.9	±29.7	±26.2	±16.8
GE [%]	5.9	7.2	7.5 [a]	7.8 [a]	8.2 [a]
	±0.9	±0.7	±0.8	±0.8	±1.0
NE [%]	12.5	17.3	18.2 [a]	19.9 [a]	19.1 [a]
	±1.5	±2.3	±3.2	±4.7	±2.4
FI [%]	24.1	21.3	19.8	20.4	17.4 [a]
	±3.4	±3.2	±3.0	±6.6	±2.7
t [s]	67.6	36.6 [a]	30.0 [ab]	26.5 [abc]	26.3 [abc]
	±4.2	±1.5	±0.0	±1.8	±2.6

[a]-averages differ significantly ($p<0.05$) between 2.5% BW and 5.0; 7.5; 10; 12.5% BW; [b]-averages differ significantly ($p<0.05$) between 5% BW and 7.5; 10; 12.5% BW; [c]-averages differ significantly ($p<0.05$) between 7.5% BW and 10; 12.5% BW; [d]-averages differ significantly ($p<0.05$) between 10% BW and 12.5% BW

The dependence of power and pedalling rate was described by the second degree polynomial for each participant (R^2=0.899-0.999). Calculated from the individual dependencies average maximal power value (P_{max}) amounted to: 1031.6±115.5 W (13.10±1.90 W/kg) by the average optimal speed v_o=109.2±12.0 rpm.

Average values (±SD) of results obtained in submaximal efforts (SM) are presented in Table 2. Mean values of produced mechanical work did not vary significantly. Average values of gross and net total energy and gross (GE) and net (NE) mechanical capacity attained by 100 rpm pedalling velocity differed crucially from outcomes reached by 40, 60 and 80 rpm pedalling rate.

Table 2
Average values (±SD) of measured in maximal efforts quantities: W_m-mechanical work; E_c-gross total energy; E_{cnet}-net total energy; GE-gross mechanical efficiency; NE-net mechanical capacity

	40 rpm	60 rpm	80 rpm	100 rpm
W_m [kJ]	44.4 ± 1.1	43.9 ± 1.6	44.0 ± 0.8	43.6 ± 0.8
E_c [kJ]	281.4 ±32.0[a]	297.2 ±31.7[a]	280.4 ±33.0[a]	347.7 ±33.1
E_{cnet} [kJ]	193.9 ±13.8[a]	192.2 ±13.8[a]	188.4 ±17.3[a]	227.3 ±33.6
GE [%]	16.0 ± 2.1[a]	15.0 ± 2.1	15.9 ± 1.9[a]	12.7 ± 1.2
NE [%]	23.0 ± 1.8[a]	22.9 ± 2.1[a]	23.5 ± 2.2[a]	19.6 ± 2.8
VO_{2net}/mass [$ml \cdot mn^{-1} \cdot kg^{-1}$]	36.61±3.27	36.30±3.11	37.57±2.73	38.76±4.41

[a]-100 rpm significantly different ($p<0.05$) with 40, 60, 80 rpm

The dependence between net VO_2 and pedalling speed was approximated for all subjects by the second degree polynomial (R^2=0.871-1.0). The average value of economical pedalling rate in submaximal efforts (SM) counted for VO_2 net amounted to: $v_{Evo2net}$=62.5±21.8 rpm and mean oxygen intake of VO_{2min}=31.56±2.98 $ml \cdot mn^{-1} \cdot kg^{-1}$ and NE v_{eNE}=62.514.8 rpm with average NE=23.9±2.5%.

Individual v_o obtained in maximal efforts (MA) correlated importantly with individual v_e from submaximal efforts and calculated from: VO_{2net} (r=-0.51; R^2=0.264; Fig. 3A) and NE (r =0.95; R^2=0.907; Fig. 3B).

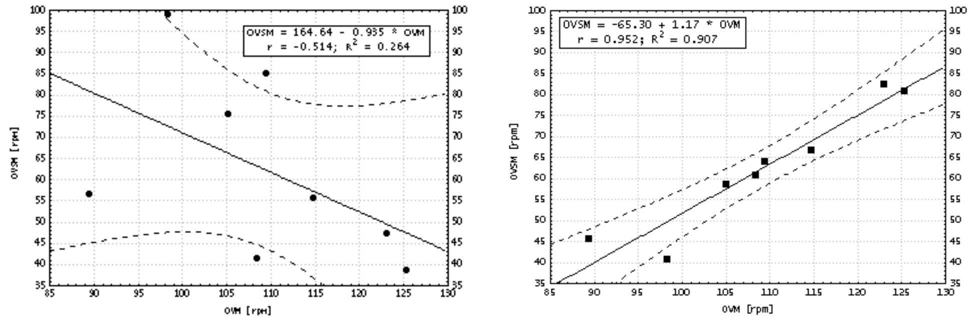

Fig. 3
Dependence of individual optimal pedalling frequency (v_o) attained in maximal efforts and individual economical pedalling rates (v_e) gained in submaximal efforts calculated from net VO_2 (A) and NE (B)

The optimal average pedalling frequency (88.9±6.9 rpm) by which the highest average power (P_m=768.3±83.6 W) was produced and economical pedalling speed equal respectively a) 85.7±14.9 rpm by which the lowest gross total energy intake occurred (E_c=216.1±46.3 kJ) and b) 97.8±10.2 rpm accompanied by the lowest net total energy intake (E_{cnet}=99.0±14.3 kJ) were calculated from the described by the second degree polynomial individual P_m-v_m and E_c-v_m dependencies (Fig. 4A and 4B). Evaluated pedalling speeds did not differ crucially.

The individual economical pedalling frequency counted in maximal efforts for the total energy correlated significantly with the individual economical pedalling velocity attained in submaximal efforts (r=0.788; R^2=0.622; Fig. 5).

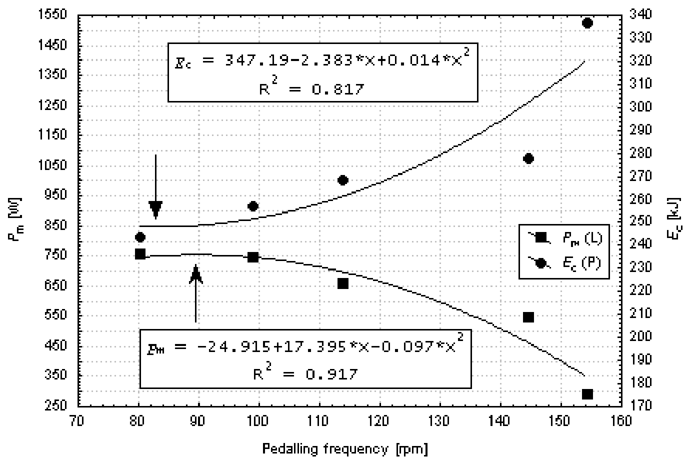

Fig. 4a
Average power (P_m) - mean pedalling velocity (v_m) and gross total energy (E_c) - average pedalling speed (v_m) dependencies obtained in maximal efforts on the cycle ergometer for mean group values. Arrows show the optimal and economical pedalling rates

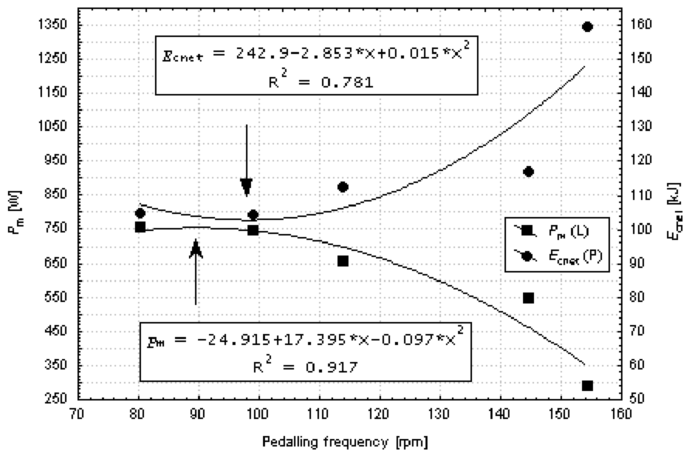

Fig. 4b
Average power (P_m) - mean pedalling velocity (v_m) and net total energy (E_{cnet}) - average pedalling speed (v_m) dependencies obtained in maximal efforts on the cycle ergometer for mean group values. Arrows show the optimal and economical pedalling rates

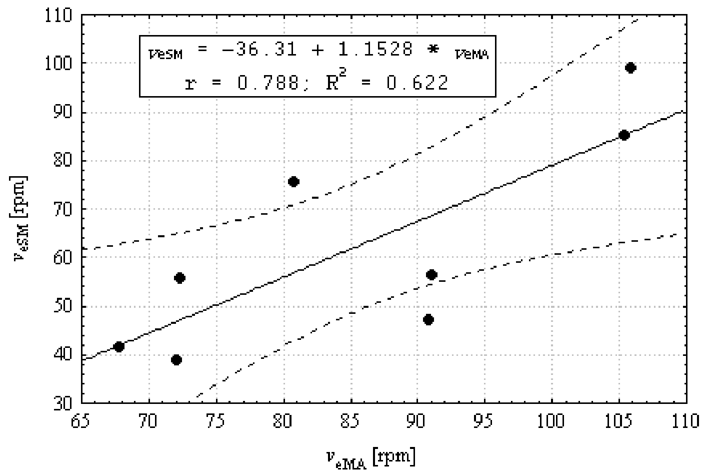

Fig. 5
Dependence of the individual pedalling rate gained in maximal efforts for total energy (v_{eMA}) and individual economical pedalling frequency (v_{eSM}) calculated from net VO_2

Discussion

The maximal power in maximal efforts is produced by the optimal pedalling speed and the force-velocity dependence (*F-v*) is described by a hyperbole or line [15,31,34,46]. Obtained in this research dependence of force from velocity was described with straight line what is in coherence with other authors' results [15,43,46]. In the study of McCartney *et al*. [31] the *F-v* characteristics were marked during 10 s efforts performed on the isokinetic cycle ergometer in the speed range of: 60-100 rpm changing every 20 s for about 20 rpm (2 min interval between the respective repetitions) and the maximal 30 s efforts were done with the pedalling frequency equal: 60, 100 and 140 rpm. The linear dependence between the power peak and frequency was noted. The power-frequency dependence was hyperbolic. The highest power (1826±287 W) was recorded by the pedalling speed equal 140 rpm and the lowest (1323±198 W) by 60 rpm. The change of pedalling rate had an influence on the maximal power value while the average power and performed work in all 30 s efforts remained similar. In the study of Hintzy *et al*. [24] the average v_o values amounted to 123.1±11.2 rpm and P_{max} to 11.1±1.6 W/kg. Arsac *et al*. [2] gained v_o=125±9 rpm and P_{max}=11.5±1.7 W/kg. Hautier *et al*. [22]

fetched v_o=120±8 rpm; P_{max}=921±200 W and P_{max}/BW=14.36±2.37 W/kg. In present research the maximal power (P_{max}) calculated from the individual *P-v* characteristics amounted to 1031.6±115.5 W (13.10±1.90 W/kg) and occurred by the optimal pedalling rate (v_o) equal 109.2±12.0 rpm. Presented in work of Hautier *et al*. [22] maximal power converted into body mass kilograms was higher than in discussed research. It could be elicited by the fact that participants of Hautier's *et al*. [22] study were trained for the sprint test and the inertial moment of the cycle ergometer fly-wheel was taken into consideration in calculations. Results attained in present work are in agreement with the references data considering the isokinetic [31,34,35] and non-isokinetic [2,24,43] cycle ergometer. In the study of Dotan and Bar-Or [16] the bigger decrease of power during the test was seen along with the increase of load. McCartney *et al*. [31] stated that the power drop depends on the pedalling speed. The higher power decrease by the higher pedalling rate was an effect of the useful work coefficient diminished according to the above authors. The lowering of the fatigue index along with the load increase was seen in present research what is contradictory to the results described by Dotan and Bar-Or [16]. It is on the other hand, in coherence with outcomes of Vandewelle *et al*. [42] who stated than the power drop during the Wingate test depends in a small degree on the effort loading. The above disagreement may be an effect of the various research techniques: our study - constant work and changeable trial time in work of Dotan and Bar-Or [16] - changeable work and constant trial time.

It seemed that the pedalling rate choice (preferred/economical) present in submaximal efforts had no use in maximal efforts where examined performed the trial with the maximal frequency. However, in this researches the optimal average pedalling frequency (88.9±6.9 rpm) by which the highest average power was produced and economical pedalling speed equal respectively a) 85.7±14.9 rpm by which the lowest gross total energy intake occurred and b) 97.8±10.2 rpm accompanied by the lowest net total energy intake were calculated from the described by the second degree polynomial individual P_m-v_m and E_c-v_m dependencies. Evaluated pedalling speeds did not differ crucially. It may be an evidence that in maximal efforts, alike in the submaximal ones, there exist some economical average pedalling speed by which the lowest energetic cost and the highest power production occurs. In the work of Wojcieszak *et al*. [45] the mechanical capacity in 30 s maximal effort amounted to 13.3%. In the study of Granier *et al*. [20] the mechanical efficiency in the Wingate test performed with the load eliciting the highest power equalled 24.6% in sprint runners and 24.5% in middle distance runners. Results attained in present paper are lower than in Granier *et al*. [20] and slightly higher from values fetched by Wojcieszak *et al*. [45]. In the study of McCartney *et al*. [31] the mechanical capacity for 30 s maximal efforts performed on the isokinetic cycle ergometer amounted respectively: 18.7-21.5% for 60 rpm; 7.5%-11.5% for 100 rpm and 1%-3% for 140 rpm. According to the above authors the mechanical capacity depends on applied load as long as the pedalling frequency is approximately stable. The pedalling rate increase on the isokinetic cycle ergometer was accompanied by the growth of power and FI. The reverse phenomenon was noted in our work for the isotonic efforts. The load increase elicited the pedalling speed diminish and connected with it growth of power and FI drop. Alike in the work of McCartney *et al*. [31] the lowest values of mechanical capacity were recorded during efforts performed with the highest pedalling rate. Nevertheless, significant differences displayed itself as regards the mechanical efficiency obtained in the effort performed with the load equal 2.5% BW and the rest of trials. These results may deny the thesis of McCartney and co. [31] that the efficiency depends on the load as long as the pedalling rate is approximately constant.

The "economical pedalling rate" term is defined in submaximal efforts as the speed by which subjects use the least amount of oxygen by applied load. Paradoxically, in spite of 50-80 rpm being the most economical frequency [5,10,11,19,30,36] cyclists prefer 90-105 rpm during long lasting efforts [21,33]. Similar behaviour was noticed in non-professional cyclists [30,41]. In the study of Marsh and Martin [30] the effort power growth did not influence the preferred pedalling rate change. Similar results achieved Pugh [32]. A few studies state that the most economical pedalling frequency grows along with the effort power [5,10]. In the paper of Böning *et al*. [5] was stated that the economical pedalling rate is increasing from 52 rpm by 50 W to 67 rpm by 200 W. In the research of Coast and Welch [10] the linear increase of the economical pedalling velocity was seen from 50 to 80 rpm by the power growth from 100 to 300 W. In the thesis of Marsh and Martin [30] the economical frequency was changing from 53.3 to 59.9 rpm along with the power increase from 75 to 200 W. The economical pedalling rate calculated in present research from the individual VO_{2net} characteristics described by the second degree polynomial amounted to 62.5±21.8 rpm what is in agreement with other studies data [9,10,30,36,44]. In the work of Hintzy *et al*. [24] the optimal frequency estimated on the basis of gross and net VO_2 was similar. The economical pedalling rate counted in our research from the gross VO_2 was lower (56.7±22.0 rpm) but the differences between gross and net VO_2 frequencies were insignificant. Many authors analyse the gross mechanical capacity measured as an external work and total energy consumption ratio without taking into consideration the resting value of VO_2. Some authors suggest that the net mechanical efficiency gives more information about actual muscle capacity [12,14,25]. In the study of Chavarren and Calbet [9] was stated that the gross mechanical efficiency diminished in cyclists along with the pedalling rate increase. The GE (gross efficiency) dependence was parabolic and was getting flat along with the power growth. Other authors also noted the GE lowering simultaneously with the pedalling speed increase and by the constant effort power [5,19,21,36]. On the other hand, Faria *et al*. [17] showed that the gross mechanical efficiency (GE) diminished in efforts with 140 W power form 18% to 14% by the pedalling rate increase from 68 to 132 rpm. However in efforts with power of 290 W it was relatively stable (22%) independently on the pedalling speed. Sidosis *et al*. [37] observed similar GE values in 280 W power effort by the pedalling rate of 60, 80 and 100 rpm. From average values of results presented in this research flows that the lowest energetic cost and the highest mechanical efficiency in the same power efforts (250 W) and work amount (around 45 kJ) and different pedalling rate was observed by 80 rpm speed. However, alike in the work of Sidossis *et al*. [37] any significant differences of GE by the pedalling rate of 40, 60 and 80 rpm were stated. In the study of Hintzy *et al*. [24] the optimum VO_2 use was determined for the 150 W submaximal effort by 60 rpm. In the research of Chavarren *et al*. [8] was stated that the influence of the pedalling speed on VO_2 decreases along with the load increase. As a consequence differences of gross mechanical efficiency are lower in highly intense exercises [10,19]. Marsh and Martin [30] observed the smallest oxygen intake in 250 W effort by the pedalling rate of 50 rpm what is in contradiction to present research outcomes although, differences between gross and net mechanical capacity obtained by pedalling frequencies equal 40, 60 and 80 rpm did not vary significantly in our work. Buśko and Kłossowski [6] did not notice significant differences between the net mechanical efficiency values attained in 5 min 150 W effort (performed work 45 kJ) by 30 and 80 rpm and NE fetched in 3 min 250 W effort with pedalling rate equal 40 and 80 rpm (done work 45 kJ). Swain and Wright [40] also did not state differences of VO_{2peak}, HR_{peak} achieved by 50 and 80 rpm speed in exercises with power of 150 W lasting for 6 min. Results of Buśko and Kłossowski [6]; Swain and Wright [40] and ours may suggest that the mechanical capacity does not depend on the effort power and its time in some pedalling speed range but on the amount of performed work.

The main discovery of present study was finding of the significant dependence between the optimal (v_o) and economical pedalling rate (negative for v_o calculated from the net VO_2 and positive for v_e counted from NE) and the significant relation between the economical pedalling frequency calculated during the maximal effort and economical pedalling speed obtained in submaximal exercise. Acquired results are only partly in coherence with outcomes of Hintzy *et al*. [24]. Mentioned authors found the positive dependence between the optimal and economical pedalling frequency calculated from the net VO_2 (R^2=0.51). Only the dependence of optimal and economical pedalling rate calculated in this research from NE was in the agreement with Hintzy's *et al*. [24] hypothesis that the individual optimal and economical pedalling pace depend on the same functional features of lower limbs muscles. It seems that evaluation of the economical pedalling speed in submaximal efforts from the net mechanical efficiency is better method of counting the v_e from VO_2 net since the NE calculation takes into consideration the amount of performed mechanical work and net total energy (the sum of VO_2 net from the whole effort + oxygen net debt). The significant relation of economical rates calculated in this research for submaximal and maximal efforts confirms the fact that economical and optimal speeds fetched for both effort kinds depend on the same biological features e.g.: muscles fibres type. It is in coherence with the result of Barany [3] who stated that the maximal velocity of muscle twitch shortening depends on a muscles fibre type. This means that person who has got the FT fibres prevalence should display higher economical pace in the submaximal effort and higher optimal and economical speed in maximal efforts. It is confirmed by other authors' studies who found the relationship between the pedalling rate and muscle fibre type in submaximal efforts [13,38] and maximal ones [22,31]. Basing on references data it seems that FT fibres may be recruited preferentially by small speed and high intensity of effort [1,18] and high velocity and small effort intensity [33,38]. This also may confirm the thesis that the same factors are responsible for the pedalling rate optimisation in submaximal and maximal efforts.

In conclusion there should be stated that produced, in maximal efforts of the same performed work on the cycle ergometer, power and mechanical efficiency grew and fatigue index value diminished along with the increase of the load put on the cycle ergometer scale. Statistically significant differences regarding the mechanical capacity were found between efforts performed with 2.5% BW and 7.5%; 10.0% and 12.5% BW. The highest maximal power was produced by the optimal pedalling rate equal 109.2 rpm. Results obtained in this research point at the occurrence of the economical pedalling speed (62.5 rpm) in efforts with power of 250 W while the least energetic cost and highest mechanical efficiency value were recorded. Statistically significant differences of mechanical capacity were stated between efforts performed with 40, 60, 80 rpm and 100 rpm. Some crucial dependencies between the optimal pedalling rate calculated in maximal efforts and economical pedalling paces in submaximal ones were noted: negative for the economical pedalling speed calculated from VO_2 net and positive for economical pedalling rate counted from the net mechanical capacity. Positive dependence between economical pedalling speeds estimated in maximal and submaximal efforts was stated.

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