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THE INFLUENCE OF PEDALLING FREQUENCY ON MECHANICAL EFFICIENCY IN EXERCISES WITH THE SAME INTENSITY

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Abstract. The aim of this work was the determination of the pedalling rate on the gross and net mechanical efficiency in efforts with the same intensity (250 W) as well as checking if the HR grows linearly along with the pedalling rate. Twelve students of AWF took part in the study. Examined subjects performed four, lasting for 3 min efforts on a cycle-ergometer (Monark E 824) joined with the computer. Exercises were done with the space of 7 days between them. The effort load equalled 250 W and the amount of performed mechanical work – 45 kJ. The pedalling rate amounted in efforts 40, 60, 80, 100 rotations per min respectively. The gas analyser (SensorMedics company) with 2900/2900c Metabolic Measurements Cart/System programme was used as for the determination of the oxygen intake during exercises and while resting (until the resting value of V_E occurs). The gross mechanical efficiency (GE) was calculated as a mechanical work and total energy ratio and the net mechanical efficiency (NE) as the mechanical work and total net energy ratio (the total energy diminished by the resting energy value). Pulse measurement was calculated during and after every effort using the POLAR-SportTester. A capillary blood was taken from a fingertip to the heparinized capillary tubes as for the estimation of an acid-alkali balance. It was done before the effort, immediately after it and in every 2 min of the 8 min rest. Following acid-alkali balance values were analysed in the blood gas analyser Ciba-Corning 248: BE, HCO_{3act}, pCO_2, pH. Average (±SD) mechanical efficiency gross values for pedalling rate of 40, 60, 80 and 100 rpm equalled respectively: 14.2±2.2, 14.9±2.6, 15.3±2.1, 12.3±1.5% and net values: 21.8±2.8, 22.6±2.1, 23.1±2.1, 19.0±2.7%. Gross and net values obtained by 100 rpm were significantly different from averages reached by 40, 60 and 80 rpm. In case of the pulse value the minimum HR occurred by the pedalling rate of 60 rpm. However, in the case of ΔHR (difference between HR value observed in the test and the resting one) the circulatory system reaction grew along with the pedalling rate. The HR values obtained by various pedalling rates did not differ crucially.

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Key words: Gross and net efficiency – Cycle ergometer

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Introduction

The ratio of the mechanical work and energy used for its completion is defined as a mechanical efficiency [3,8,48] or a useful work coefficient [31]. The mechanical efficiency of the isolated muscle equals from 20 to 25% [4]. As considering the mechanical efficiency calculation in chosen motion acts bigger diversification of obtained results was observed. Basing on references, changes of the mechanical efficiency values from 2 to 80% can be stated depending on: working limb [46], work dimension and the time of its performance [49], kind of conducted exercises (eccentric, concentric or mixed) [3,4], kind of practised sport discipline [36], kind of muscles fibres (ST, FT) [5] or the accepted calculation methods (running speed calculated basing on the film [25] or as a treadmill speed [31]). The mechanical efficiency is usually used for the human motion output description. The better dexterity is connected with the higher level of achievements in various sport disciplines [16,28].

The term: "optimal/economical pedalling rate" is defined as the pedalling frequency by which examined subjects use least of all oxygen amount. The optimal speed was noticed by 60 to 100 rpm [14,21,34,41]. Few researchers observed that the economical pedalling pace value grows together with the power of performed on the cycle-ergometer effort [7,14,39]. In the work of Marsh and Martin [30] the economical pedalling rate equalled in all efforts (75, 100, 150 and 200 W) 50 rpm. Similar oxygen intake was noticed for 200 W by pedalling speed of 50 and 65 rpm. The most economical pedalling rate, calculated from the second degree polynomial, amounted in cyclists to 59.9 rpm and in runners to 56.5 rpm. Results of Marsh and Martin [30] are not coherent with other authors results who observed the increase of the economical pedalling pace along with the effort power e.g.: Seabury *et al.* [39] from 42 rpm for 41 W to 62 rpm for 327 W; Böning *et al.* [7] from 52 rpm for 50 W to 67 rpm for 200 W and Coast and Welch [14] from 50 rpm for 100 W to 80 rpm for 300 W.

Many works are concentrated on the gross mechanical efficiency (GE) analysis for it is easy to measure and needs no correction concerning the resting oxygen intake [20]. It is believed that the net mechanical efficiency (NE) characterises better the bicycle riding technique [16,23]. Calculated gross mechanical efficiency grew when the pedalling rate was increasing from 40 to 60 rpm and next, did not change by 80 and 100 rpm [13,14,34]. Results from the other few papers show that the gross efficiency was growing along with the load [14,20,39]. Additionally, in works of Hagberg *et al.* [21] and Seabury *et al.* [39] the energetic output was growing with the pedalling rate increase by the load of 0 W.

The dependence between the heart retraction (HR) and the pedalling speed is not fully recognised. In the work of Hagberg *et al.* [21] the linear HR growth along with the pedalling rate in efforts with constant power was noticed. In the study of Kippelen *et al.* [27] this dependence was curvilinear. The lowest pulse values were recognised by 80 rpm (around 164.9 beats$\cdot$min^{-1}). The 60 rpm resulted in pulse equal 165.9 beats$\cdot$min^{-1} and 100 rpm in 168.4 beats$\cdot$min^{-1}.

The aim of this work was the determination of the pedalling rate on the gross and net mechanical efficiency in efforts with the same intensity (250 W) as well as checking if the HR grows linearly along with the pedalling speed.

Material and Methods

Twelve students of AWF took part in the study. Subjects characteristics were: age – 20.7±6.5 years; body height – 180.1±6.2 cm; body mass – 79±10.1 kg.

The study was accepted by the Senate Scientific Research Board of Ethics by the Academy of Physical Education in Warsaw. Participants were informed about the research goal and methodology. They were also informed about the possibility of the immediate resignation in every stage of the study. Examined subjects accepted the above conditions in written.

Experiment: Before the experiment beginning examined subjects acknowledged the methodology of research. They performed four, 3 min efforts on the cycle-ergometer (Monark E 824, Sweden) joined with the computer IBM PC Pentium with the “MCE v. 4.0” programme (“JBA” Z.Staniak, Poland). Exercises were done with the space of 7 days between them. The effort power equalled 250 W and the amount of performed mechanical work – 45 kJ. The pedalling rate amounted in efforts respectively: 40, 60, 80, 100 rpm. Gauges were put on the fly-wheel which made a distance of 6 m while one pedals circle. Examined performed tests in the sitting position without standing on pedals and beginning motionless. Feet were fasten to pedals with straps. Measurements and calculations of: average power (P_m), amount of performed mechanical work (W_m) and time of effort were done using the “MCE v. 4.0” programme.

The gas analyser (SensorMedics, USA) with the 2900/2900c Metabolic Measurements Cart/System software was used for the determination of the oxygen intake during cycle-ergometer exercises and in the resting phase (till V_E goes back to the obtained resting value). Ventilation and changes of the gas variable were monitored breath-by-breath and averaged every 20 s in a system of open ventilation. Before every examination the gas analyser was calibrated with specifically concentrated O_2 and CO_2 gases (AGA Gas BV, Holland).

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

Accordingly to previous works of Coast and Welch [14], Gaesser and Brooks [20], Mintzy *et al.* [22], Marsh and Martin [29], Seabury *et al.* [39] the optimal pedalling rate was calculated from the individual second degree polynomial equations which were used for the denotation of VO_{2net} pedalling rate dependence. The lowest point of the curve was defined as the optimal (the most economical) pedalling speed (Fig. 1). The average oxygen intake in the third effort min was used for the VO_{2net} pedalling rate dependence indication.

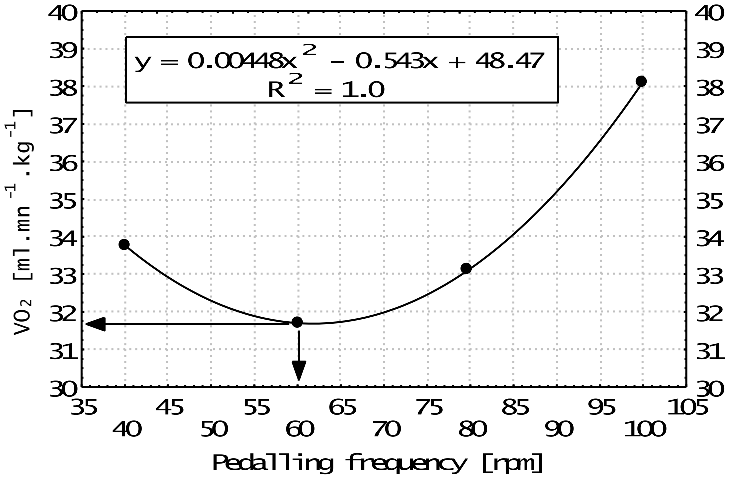

Fig. 1
Exemplary dependence of VO_{2net} – pedalling rate of one examined subject.
Arrows determine the optimal pedalling speed and the minimal oxygen intake during effort with load equal 250 W

The pulse measurement was conducted during and after the effort using the POLAR-SportTester (OY, Finland).

The capillary blood was taken from a fingertip to the heparinized capillary tubes as for the estimation of the acid-alkali balance. It was done before, immediately after the effort and in every 2 min of the 8 min rest. Following acid-alkali balance values were analysed in the blood gas analyser Ciba-Corning 248 (G.B.): BE, $HCO_{3act,}$ pCO_2, pH.

All measurements were conducted in the morning.

The MANOVA analysis of variance was used as for the research results verification. The significance of differences between averages was compared post hoc – using the Tukey's test. The acid-alkali balance analysis was done using the ANOVA (4x6) analysis with repeated measuring system. The significance of the averages difference was compared post hoc – using the LSD test. The degree of dependence between the VO_2 and body mass was determined basing on the Pearson's correlation coefficients. All the measurements were conducted using the STATISTICA™ (V. 5.5, StatSoft, USA) software.

Results

Average (±SD) values of obtained results are presented in Table 1. The value of mechanical work performed on the cycle-ergometer was changing from 42.5 kJ to 45.6 kJ for 40 rpm; from 42.3 kJ to 44.7 kJ for 80 rpm and from 41.8 kJ to 44.4 kJ for 100 rpm. Average mechanical work values did not differ crucially.

Mean gross and net total energy and gross and net mechanical efficiency values accomplished by 100 rpm varied significantly from results achieved by 40, 60 and 80 rpm.

Table 1

Measured parameters mean values (±SD): W_m – mechanical work; E_t – total gross energy; E_{tnet} – total net energy; GE – gross mechanical efficiency; NE – net mechanical efficiency; HR – heart rate; ΔHR – difference between the HR and resting HR value

Variable	40 rpm	60 rpm	80 rpm	100 rpm
W_m (kJ)	44.1±1.14	43.7±1.4	43.8±0.68	43.6±0.7
E_t (kJ)	297.8±36.2^a	299.3±43.0^a	291.4±39.7^a	358.1±44.2
E_{tnet} (kJ)	205.2±28.2^a	194.0±15.7^a	191.3±16.2^a	233.1±34.2
GE (%)	15.0±2.2^a	14.9±2.6^a	15.3±2.1^a	12.3±1.5
NE (%)	21.8±2.8^a	22.6±2.1^a	23.1±2.1^a	19.0±2.7
HR (beats$\cdot$min^{-1})	163.6±14.9	161.5±16.8	165.3±13.5	171.7±11.4
ΔHR (beats$\cdot$min^{-1})	83.2±12.9^a	84.8±15.2	87.3±13.7	95.2±15.9

- averages differ significantly from mean 100 rpm; ^{a} - $P<0.05$

Average HR values registered during efforts performed with different pedalling rates did not disparate essentially (Fig. 2).

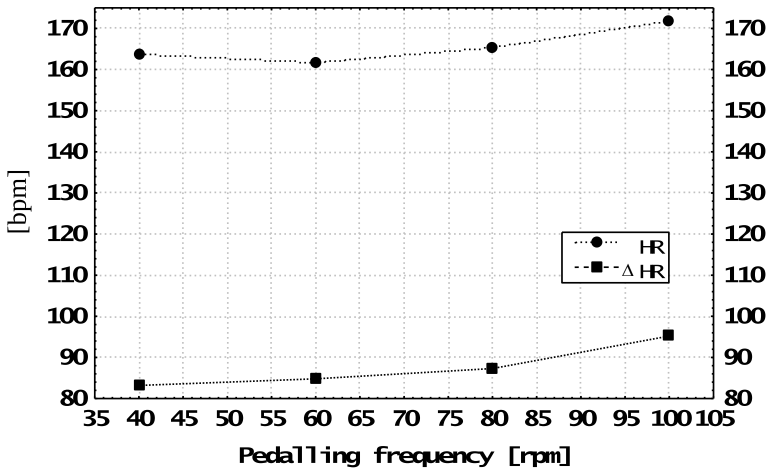

Fig. 2
Average HR and ΔHR values obtained during the effort with 250 W power and the pedalling rate of 40, 60, 80 and 100 rpm

Changes of average (±SD) values of the acid-alkali balance elicited by efforts with various pedalling paces were presented on the Fig. 3. The smallest acid-alkali balance changes ($P<0.05$) caused efforts performed with the pedalling speed of 40 and 60 rpm. Any essential differences between the acid-alkali balance changes elicited by this effort were stated (Table 2A, 2B). Some crucial differences occurred after efforts with the pedalling rate equal 100 rpm.

Discussion

The skill of proper pedalling rate selection is one of the major agents helping in gaining cycling success. Paradoxically, although the most economical (efficient) pedalling rate is 50-80 rpm [7,13,14,20,30,39] cyclists prefer the speed of 90-105 rpm during long efforts with high intensity [21,38]. Similar behaviour was noticed in unprofessional cyclists [30,45]. Hence, a few theories were created as for the above phenomenon explanation. The higher pedalling rate elicits: smaller stress and tiredness [32,33,44,45]; lower glycogen intake [1]; optimal application of force to pedals (optimal pressure on pedals) [18,26,37]. Moreover, some authors stated that the bio-mechanical variables such as: force on pedals, joints force moments and muscle power are minimised by the higher pedalling speed and next, that if the power grows the pedalling rate has to grow as for the variable minimisation [24,33,35]. In the work of Patterson and Moreno [33] was noticed that the force put on pedals was the smallest by the pedalling pace of 90-100 rpm during efforts with load equal 100 and 200 W respectively. Redfield and Hull [35] and Hull *et al.* [24] showed in the computer simulation that the pedalling rate of 95-100 rpm minimizes the average force moments in joints and the muscle power as well. The above forces influenced pedals pushing in cycling with the load of 200 W. Nevertheless,

Table 2A
HCO_3 and BE (mean±SD) in the trial at pedal rates of 40, 60, 80 and 100 rpm during rest (RE), immediately after end of the trial (0), and at 2, 4, 6, and 8 min of the recovery period

	Rates	RE	0	2'	4'	6'	8'
HCO_{3act} ($mmol \cdot l^{-1}$)	40	24.60 ±1.81	21.06*^{a} ±1.84	18.59*^{ab} ±2.23	18.53*^{ab} ±2.38	18.53*^{ab} ±2.11	19.18*^{ab} ±1.91
	60	24.93 ±1.90	20.84*^{a} ±2.62	18.53*^{ab} ±3.25	18.38*^{a} ±3.49	18.82*^{ab} ±3.09	19.51*^{ab} ±3.20
	80	24.30 ±1.33	20.36*^{a} ±1.83	17.13*^{a} ±2.08	17.40*^{a} ±2.40	17.48*^{a} ±2.55	17.98* ±2.34
	100	24.21 ±2.10	19.03* ±2.32	16.23* ±2.25	15.93* ±3.17	16.22* ±2.99	16.43* ±3.04
BE ($mmol \cdot l^{-1}$)	40	-0.21 ±1.68	-5.56*^{a} ±2.05	-7.42*^{ab} ±2.53	-7.31*^{ab} ±2.72	-6.91*^{ab} ±2.59	-6.03*^{a} ±2.29
	60	0.03 ±1.65	-5.62*^{a} ±2.80	-7.29*^{ab} ±3.40	-7.30*^{a} ±3.57	-6.68*^{ab} ±3.45	-5.76*^{ab} ±3.49
	80	-0.52 ±0.98	-6.15*^{a} ±1.86	-8.72*^{a} ±2.23	-8.43*^{a} ±2.67	-8.06*^{a} ±2.98	-7.22* ±2.82
	100	-0.43 ±1.90	-7.38* ±2.66	-9.83* ±2.77	-10.01* ±3.77	-9.55* ±3.72	-8.85* ±3.83

-significantly different with RE, * - $P<0.05$
-significantly different with 100 rpm, ^{a} $P<0.05$
-significantly different with 80 rpm, ^{b} - $P<0.05$

the definite answer for the question why the pedalling rate with lower mechanical efficiency and not the most economical one is chosen by cyclists was not gained. References state that during the preferred rate the pedalling causes bigger oxygen usage in comparison to the optimal pace when the oxygen intake is the lowest. In the work of Marsh and Martin [30] the preferred rate was decreasing in non-athletes along with the growth of the effort power from 80 (75 W) to 60 rpm (175 W). As considering cyclists and long distance runners it amounted around 91-94 rpm independently on the load. Next, the oxygen intake grew along with the pedalling rate increase independently on the load of 100, 150 and 200 W. The smallest one was observed by 56-60 rpm.

Table 2B
pH and PCO_2 (mean±SD) in the trial at pedal rates of 40, 60, 80 and 100 rpm during rest (RE), immediately after end of the trial (0), and at 2, 4, 6, and 8 min of the recovery period

	Rates	RE	0	2’	4’	6’	8’
pH	40	7.398 ±0.017	7.287* ±0.037	7.291* [a] ±0.050	7.297* ±0.048	7.315* [a] ±0.052	7.330* ±0.046
	60	7.388 ±0.024	7.293* [a] ±0.043	7.298* [a] ±0.045	7.303* [a] ±0.045	7.316* [a] ±0.052	7.331* [a] ±0.051
	80	7.395 ±0.013	7.286* ±0.037	7.285* ±0.051	7.288* ±0.053	7.301* ±0.054	7.321* ±0.057
	100	7.402 ±0.027	7.278* ±0.048	7.267* ±0.055	7.270* ±0.063	7.286* ±0.068	7.302* ±0.071
pCO2 (mmHg)	40	40.77 ±2.58	45.16* [a] ±4.03	39.47 [ab] ±4.90	38.72 [a] ±4.22	37.23* [a] ±4.09	37.23* [ab] ±3.91
	60	42.35 ±3.12	43.40 ±5.22	38.51* [a] ±4.66	37.63* [a] ±5.15	37.45* [a] ±4.13	37.50* [ab] ±4.21
	80	40.58 ±3.0	43.78* [a] ±4.86	37.04* ±6.05	37.18* [a] ±5.72	36.14* [a] ±4.60	35.57* ±4.54
	100	39.84 ±3.65	41.58 ±4.33	36.38* ±4.41	34.89* ±4.06	33.94* ±3.42	33.68* ±3.47

-significantly different with RE, * - $P<0.05$
-significantly different with 100 rpm, [a] $P<0.05$
-significantly different with 80 rpm, [b] - $P<0.05$

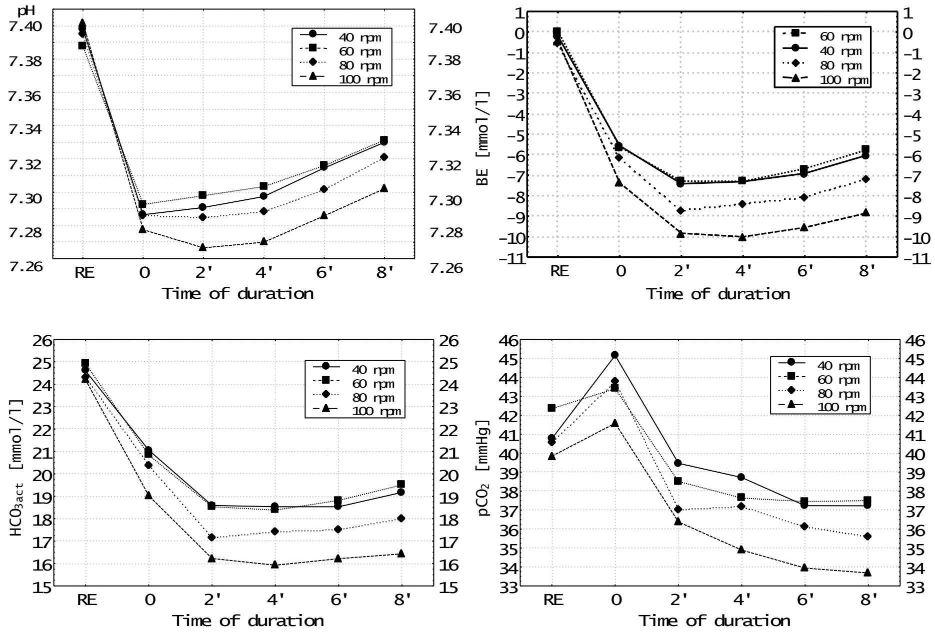

Fig. 3
Changes of the average pH, BE, HCO_{3act} and pCO_2 values influenced by the efforts with 250 W load performed with the pedalling rate equal 40, 60, 80 and 100 rpm (RE – resting values; 0 – measurement conducted immediately after the effort and in 2’, 4’, 6’ and 8’ of the recovery)

The skill of proper pedalling rate selection is one of the major agents helping in gaining cycling success. Paradoxically, although the most economical (efficient) pedalling rate is 50-80 rpm [7,13,14,20,30,39] cyclists prefer the speed of 90-105 rpm during long efforts with high intensity [21,38]. Similar behaviour was noticed in unprofessional cyclists [30,45]. Hence, a few theories were created as for the above phenomenon explanation. The higher pedalling rate elicits: smaller stress and tiredness [32,33,44,45]; lower glycogen intake [1]; optimal application of force to pedals (optimal pressure on pedals) [18,26,37]. Moreover, some authors stated that the bio-mechanical variables such as: force on pedals, joints force moments and muscle power are minimised by the higher pedalling speed and next, that if the power grows the pedalling rate has to grow as for the variable minimisation [24,33,35]. In the work of Patterson and Moreno [33] was noticed that the force put on pedals was the smallest by the pedalling pace of 90-100 rpm during efforts with load equal 100 and 200 W respectively. Redfield and Hull [35] and Hull *et al.* [24] showed in the computer simulation that the pedalling rate of 95-100 rpm minimizes the average force moments in joints and the muscle power as well. The above forces influenced pedals pushing in cycling with the load of 200 W. Nevertheless, the definite answer for the question why the pedalling rate with lower mechanical efficiency and not the most economical one is chosen by cyclists was not gained. References state that during the preferred rate the pedalling causes bigger oxygen usage in comparison to the optimal pace when the oxygen intake is the lowest. In the work of Marsh and Martin [30] the preferred rate was decreasing in non-athletes along with the growth of the effort power from 80 (75 W) to 60 rpm (175 W). As considering cyclists and long distance runners it amounted around 91-94 rpm independently on the load. Next, the oxygen intake grew along with the pedalling rate increase independently on the load of 100, 150 and 200 W. The smallest one was observed by 56-60 rpm.

Similar preferred pedaling rate was depicted by Marsh and Martin [29] in cyclists and non-athletes (85.2 and 91.6 rpm respectively). In researches of Marsh and Martin [30] the growth of the effort power did not influence significantly the change of preferred pedalling speed. Congenial results were observed by Pugh [34]. In presented work examined subjects chose the pedalling rate of 80 rpm. The highest average values of the mechanical efficiency were observed during cycling with this pedalling pace exactly. It is coherent with the work of Hagberg *et al.* [21] presenting similar phenomenon. In next couple of works the most economical pedalling speed grow altogether with the effort power was noticed [7,14]. In the study of Böning *et al.* [7] the tendency of the economic pedalling rate enlarging from 52 rpm by 50 W to 67 rpm by 200W was observed. In the research of Coast and Welch [14] the linear growth of the economic pedalling pace from 50 to 80 rpm by the power increase from 100 to 300 W was seen. In the study of Marsh and Martin [30] the economical pedalling speed was changing from 53.3 to 59.9 rpm simultaneously with the power increase from 75 to 200 W. In this research the economic pedalling rate, calculated from the individual characteristics VO_{2net} depicted by the second degree polynomial, amounted to 61.7±17.6 rpm and it is congenial with the previous works results [12,14,30,39,46]. In the work of Hintzy *et al.* [22] the optimal pedalling rate calculated from the gross and net VO_2 was similar. In presented study the optimal pedalling pace counted from the gross VO_2 was lower (55.8±23.1 rpm) but differences between the gross and net rates were not statistically significant. Many authors analyze the gross mechanical efficiency calculated as an exterior work and total energy consumption ratio without taking into consideration the correction for the resting VO_2 value. Some of the authors suggest that the net mechanical efficiency gives more information about the actual muscle possibilities [15,16,23]. In the study of Chavarren and Calbet [12] the gross mechanical efficiency decrease was noticed in cyclists along with the increase of the pedalling rate.

The GE-rate dependency was parabolic but it got flatten simultaneously with the effort power (intensity) increase. Other authors also observed the GE decrease along with the increase of the pedalling rate in efforts with stable power [7,20,21,39]. On the other hand, Faria *et al.* [19] described that the gross mechanical efficiency was falling from 18 to 14% by the pedalling rate raise from 68 to 132 rpm during efforts with 140 W. However, while efforts with power equal 290 W the GE was relatively balanced and amounted around 22% independently on the pedalling pace. Sidassis *et al.* [40] noticed alike GE values by the pedalling rate of 60, 80 and 100 rpm and effort power - 280 W. From the comparison of the above researches results springs that the lowest energetic output and the highest mechanical efficiency in efforts with the same load (250 W) and amount of performed work (45 kJ), diversified by the pedalling rate, was observed by the pedalling pace equal 80 rpm. Nonetheless, similarly as in the work of Sidossis *et al.* [40] the significant GE differences were not observed by the pedalling rate of 40, 60 and 80 rpm. In the study of Hintzy *et al.* [22] the optimal VO_2 intake was seen by the sub-maximal effort (150 W) and pedalling speed of 60 rpm. Chavarren *et al.* [11] stated that the influence of the pedalling rate on VO_2 is decreasing together with the load grow. As a consequence, the gross mechanical efficiency differences were lower by the higher intensities of exercises [14,20]. Marsh and Martin [30] observed the lowest oxygen intake in effort of 250 W load and the pedalling pace of 50 rpm what is not congenial with results of presented earlier researches. Albeit, differences between the gross and net mechanical efficiency achieved by the pedalling speed of 40, 60 and 80 rpm did not vary significantly in this work. Buśko and Kłossowski [9] who compared the net mechanical efficiency values acquired during the 5 min effort (150 W, 45 kJ) and pedalling pace: 30 rpm - NE=23.2% and 80 rpm - NE=21.9% with the NE reached during the 3 min exercise (250 W, 45 kJ) and pedalling rate: 40 and 80 rpm did not notice some crucial differences. Also Swain and Wright [41] did not state differences of VO_{2peak} and HR_{peak} attained by the rate of 50 and 80 rpm in 6 min exercises with load of 150 W. Presented work results, results of Buśko and Kłossowski [9] and Swain and Wright [41] may imply that the mechanical efficiency is not depended on the effort power and time of its performance but rather on the value of work itself.

The pulse (HR) value is one of the physiological markers influenced by the pedalling rate [21]. In the work of Buśko [10] statistically significant differences were observed for ΔHR (difference between the HR value noted during the test and the resting one) during the 5 min sub-maximal effort (150 W) performed with high – 80 rpm and low – 30 rpm pedalling speed. Although the examined subjects performed bigger realistic work (45.7±2.1) during effort with 30 rpm, their circulatory system reacted more softly (ΔHR=59.5±13.7 beats·min^{-1}) and the oxygen intake was close to this obtained by 80 rpm speed (W_m=43.5±0.8 kJ; ΔHR=69.2±11.8 beats·min^{-1}). The work of Hagberg *et al.* [21] showed the linear growth of HR together with the pedalling rate increase in efforts with the stable load. In the paper of Croisant and Boileau [17] the function was fixed with the smallest squares method. In the study of Coast and Welch [14] the optimal pedalling pace, for 3 min efforts performed with various pedalling rates (40-120 rpm) and load of 250 W, calculated from the oxygen intake amounted to 66 rpm and counted from the HR/pedalling speed dependence to 70 rpm. The lowest HR values were recorded in efforts performed with the pedalling rate equal 60 rpm. The HR values noticed in efforts with various pedalling speed differed significantly except the HR values observed by 60 and 80 rpm. Similar results were reached in this research. As considering the pulse values the minimum HR was seen by the pedalling pace equal 60 rpm. In case of ΔHR the circulatory system reaction was growing along with the pedalling rate. Presented in this work HR values and the local minimum occurrence for the pulse speed are coherent with results of Kippelen *et al.* [27] who registered the lowest pulse values in cyclists at the level equal 80% VO_2max by 80 rpm (around 164.9 beats·min^{-1}). The pulse equaled 165.9 and 168.9 beats·min^{-1} by pedalling pace of 60 and 100 rpm respectively. As well in the work of Chavarren and Calbet [12] the lowest HR was observed by the pedalling rate of 80 rpm and the optimal GE by 60 rpm during effort with 259 W load. The above authors reckon that HR is the index of exercises intensity and not the pedalling rate effect.

The body mass influence on VO_2 and the mechanical efficiency during efforts on the cycle-ergometer is traditionally regarded as unimportant [2]. However, in the study of Williams *et al.* [47] some significant positive correlation of VO_2 and body mass during low load effort (29 and 56 W) and negative during effort with 136 W was found. In the work of Berry *et al.* [6] crucial relationship of body mass and gross VO_2 (r=0.80 for the 60 rpm and r=0.71 for 90 rpm pedalling speed) and net VO_2 (r=0.63 for 60 rpm and r=0.48 for 90 rpm pedalling rate) was noted. This research proved the existence of relation between the body mass and the gross VO_2 (r_G=0.85; P<0.05) and net VO_2 (r_N=0.47) during the effort with 60 rpm pedalling pace and respectively r_G=0.47 and r_N=0.34 for the speed of 80 rpm. In case of efforts conducted with the 40 and 100 rpm the correlation coefficient value were comprised between 0.06-0.20. It seems as if there existed some relationship of the body mass and oxygen intake in efforts performed on the cycle-ergometer and the pedalling rate equal 60-80 rpm.

To sum up, results achieved in this research point at the occurrence of such a pedalling rate in efforts with load of 250 W, which elicits the lowest energetic cost and highest gross and net mechanical efficiency. The statistically significant gross and net mechanical efficiency was seen between efforts performed with the pedalling speed of 40, 60, 80 and 100 rpm. As considering the pulse the minimum HR was observed by 60 rpm. HR values obtained by various pedalling rates did not differ significantly. The reaction of the circulatory system measured as ΔHR was growing along with the pedalling pace increase. Attained in this research relations of body mass and oxygen intake point at the existence of the body mass influence on VO_2 however, only in a restricted pedalling rate range (60-80 rpm).

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