Biology of Sport, Vol. 23 N°1, 2006

CHANGES OF FORCE-VELOCITY AND POWER-VELOCITY RELATIONSHIPS AFTER TRAINING PERFORMED ON CYCLE ERGOMETER

K. Buśko

Dept. of Biomechanics, Institute of Sport, Trylogii 2/16, 01-982 Warsaw, Poland
Dept. of Biometry, Academy of Physical Education, Warsaw, Poland

Abstract. The aim of this work was the examination of lower limbs muscles force-velocity and power-velocity characteristics changes during the cycle ergometer training. Students of Academy of Physical Education in number of 43 took part in the research. They were divided in 4 groups and performed various velocity cycle ergometer training. The training encompassed 5 intermittent efforts parted with 2 min pause: group M10 – maximal efforts with the load equal 10% BW, group M5 – maximal efforts with load of 5% BW, group W80 – 3 min efforts with power equal 250 W and pedalling rate of 80 rpm, group W45 – 3 min efforts with power of 250 W and pedalling velocity equal 45 rpm. Control measurements of force-velocity (*F-v*) and power-velocity (*P-v*) relationships were taken each Monday before training beginning, during 4 weeks of the experiment and 2 weeks after it. The *F-v* simple regression equation average direction coefficients gained in all groups during 4 training weeks and after the 1st and 2nd week from testing differed significantly according to data gathered before the research. The *F-v* simple regression equation direction coefficients varied significantly between groups M10 and M5 and between W80 and W45 after the 1st week from tests next, between M5 and W80, W45 after the 2nd week of resting period. The highest increase of power output measured in *P-v* characteristics was observed in groups M5 and M10 after the 1st week from the experiment by following loads: 2.5%, 5.0% and 7.5% BW and in groups W45 and W80 immediately after 4 week training by loads of 10.0% and 12.5% BW. The lack of crucial differences among groups suggest that the pedalling rates used in trainings had no influence on the after training power output during *F-v* and *P-v* characteristics determination. The training intensity effects the simple force-velocity relationship direction coefficients.

(Biol.Sport 23:17-32, 2006)

Key words: Cycle ergometer training – Force-velocity relationship – Power-velocity relationship – Power output

---

Reprint request to: Dr Krzysztof Buśko, Dept. of Biomechanics, Institute of Sport, Trylogii 2/16, 01-982 Warsaw, Poland
E-mail: krzbusko@poczta.onet.pl; E-mail: krzysztof.busko@insp.waw.pl

Introduction

Human ability of power production in short time plays an important role in many sports disciplines and in every day activity. Power depends on strength and velocity. Strength and velocity as power compounds are frequently trained separately. Increase of maximal force or velocity or both under the influence of training improved maximal power of muscles [6,7,8,17]. However, according to Bell *et al.* [1] the improvement of strength not necessarily betters power since large part of the after effort force is neurologically based [26]. Häkkinen [8] in his work showed that training consisting of large loads exercises eliciting about maximal force values and relatively small motion velocity improves mainly this part of force-velocity (*F*-*v*) curve which lies in the field of small rates while exercises performed with large velocities and small force influence the whole *F*-*v* characteristic. Kanehisa and Miyashita [15] stated that training with heavy weights lifted in slow motion elicits enlargement of maximal power and force in motions with small velocities while the dynamic lifting of light weight increases strength and power in the field of large velocities. Similar after training changes were observed for training performed on the isokinetic dynamometer with large and small velocity [3,5].

There are only few works in references regarding changes of force-velocity (*F*-*v*) and power-velocity (*P*-*v*) characteristics under the influence of the cycle ergometer training [17,18,19] and there are any descriptions of the effect of pedalling rate on after effort changes of the above characteristics. In the light of this fact it seems worth examining the various velocity cycle ergometer exercises effect on *F*-*v* and *P*-*v* relationships.

The aim of this work was the examination of lower limbs muscles force-velocity and power-velocity characteristics changes during the cycle ergometer training.

Materials and Methods

The research was conducted on 43 students of Academy of Physical Education who were divided into 4 groups. They performed training on a cycle ergometer composed of 5 efforts paused by 2 min intervals: group M10 (n=9) – maximal efforts with load equal 10% body weight (BW), group M5 (n=11) – maximal efforts with 5% BW, group W80 (n=11) – 3 min efforts with power equal 250 W and pedalling rate equal 80 rotations per minute (rpm), group W45 (n=12) – 3 min efforts with power of 250 W and pedalling velocity of 45 rpm. Examined subjects characteristics are presented in Table 1. As considering the anthropometric features groups did not differ significantly.

Table 1
Examined groups characteristic (averages ± SD)

Groups		Age (years)	Body height (cm)	Body weight (kg)
M10	(n=9)	22.2±1.8	178.1±6.5	77.8±10.5
M5	(n=11)	22.5±0.9	180.7±7.6	78.0±11.1
W80	(n=11)	23.3±1.1	182.8±7.9	80.3±12.1
W45	(n=12)	22.7±1.4	182.1±6.5	79.7±9.6

Maximal efforts training with loads: 10% BW – group M10, 5% BW – group M5, 3 min efforts intermittent training with power of 250 W and pedalling rates: 80 rpm – group W80 and 45 rpm – group W45

This research was accepted by the Ethics Committee for Scientific Research. All the participants were informed about the aim and methodology of the experiment. They were aware that they can resign at any stage of researches. Examined students accepted the above conditions in written. All measurements were conducted in mornings.

Experiment: At the very beginning of this experiment all students acknowledged all types of measurement and performed the Wingate test (load 7,5% body weight) on the cycle ergometer Monark 824E (Sweden) according to the standard methodology described by Inbar *et al.* [13].

All groups' participants for 4 weeks, 4 times a week performed training on the Monark 824E cycle ergometer attached to a computer equipped with the MCE v. 4.0 programme (JBA Zb. Staniak, Poland). Test and trainings were done sitting, without standing on pedals and riding began from the motionless position. Feet were fastened to pedals with straps. The experiment participants were encouraged to gain the maximal velocity as fast as they were able and keep it until the end of the test. In a case of the 3 min efforts with power of 250 W examined had to keep the constant pedalling rate. Measurements and calculations of the maximal power, amount of performed work and times of work and rest were obtained using the "MCE" programme. The singular training encompassed:

- group M10 – 5 maximal efforts: first – 100% of work determined in the Wingate test (19.36±2.58 kJ), other four – 50% of the above work (4 x 9,68±1,29 kJ). The external loads being equal 10% of the body weight (BW). The interval between trainings equalled 2 min.

- group M5 – 5 maximal efforts: first – 100% of work determined in the Wingate test (19.16±2.30 kJ), other four – 50% of the above work (4 x 9,579±1,151 kJ) The external loads being equal 5% BW. The interval between trainings equalled 2 min.
- group W80 – 5 lasting for 3 min efforts with the power of 250 W and work of about 45kJ (pedalling rate 80 rpm, load 31.0 N appended on the cycle ergometer scale). The interval between trainings equalled 2 min.
- group W45 – 5 lasting for 3 min efforts with the power of 250 W and work of about 45 kJ (the pedalling rate 45 rpm, load 55.0 N appended on the cycle ergometer scale). The interval between trainings equalled 2 min.

The aim of such a specific load appended on the cycle ergometer scale in groups M10 and M5 was the manipulation of muscles work influencing directly the pedalling rate in every maximal effort. Load equalling 10% BW elicited lower average pedalling velocity in comparison to lower load of 5% BW what as a consequence forced various intensity of training.

Students did not perform additional trainings and used no nutrition supplementation throughout the experiment.

Force-velocity and power-velocity characteristics were marked each Monday before the testing (0), for 4 weeks of training (1-4) and 2 weeks after the testing (5-6).

Force-velocity (*F-v*) and power-velocity (*P-v*) characteristic was performed on the Monark 824E (Sweden) cycle ergometer attached to a computer IBM PC Pentium with “MCE v. 4.0” software (JBA Zb. Staniak, Poland). Sensors were put on the flying-wheel making 6 m distance during one circle of pedals. Examined after fasting their saddle and wheel performed test in the sitting position without standing on pedals and beginning riding motionless. Feet were fastened to pedals with straps. Subjects done 5 maximal 10 s efforts with rising external load from 2.5%; 5.0%; 7.5%; 10.0% to 12.5% BW. The interval between respective efforts lasted for 2 min. Students were eagerly spurred for gaining the maximal pedalling velocity as fast as they could and then keeping it as long as it was possible. Using the “MCE v. 4.0” software the measuring and calculations of the highest produced by respective loads power (P_n where n = load value) and velocity (v_n by which P_n was reached) were done. The *F-v* and *P-v* relationships was determined for each examined subject basing on their results obtained in 10 s maximal efforts. Maximal power and optimal velocity of pedalling were calculated from individual equations of a second order polynomial which was used to describe the *P-v* relationship

[2,18]. The highest point of the curve (highest value of the function) was defined as maximal power and the frequency of pedalling corresponding to it as optimal velocity [18].

Force-velocity and power-velocity characteristics results were compared through ANOVA/MANOVA analysis with repeated measurements. The significance of average differences were examined post hoc with the LSD test (least significant difference test). All calculations were done using the Statistica ™ v 5.5 programme (StatSoft, Inc. USA).

Results

The *F-v* relationships were described in examined groups by a straight line. Average values of the direction coefficients of simple *F-v* regression equation differed significantly after 4 weeks of training and after the 1st and 2nd week from it in relation to values obtained before the whole experiment (Table 2). Subjects under the maximal efforts displayed crucial differences between direction coefficients of the simple *F-v* regression equation gained after the 1st week from testing and obtained immediately after 4 week training. Some significant variations of the simple *F-v* regression equation direction coefficients were noticed between

Table 2
Average values (±SD) of the direction coefficient of force-velocity relationship simple regression equation and the significance of differences between averages measured before the experiment (0) and following ones: (4) – after 4 week training; (5-6) – 2 week after training period (*-p<0.05).

	0	4	5	6
M10	0.0967±0.0090	0.1098±0.0095*	0.0969±0.0147#	0.1077±0.0132*^{o}
M5	0.1005±0.0113	0.1051±0.0108	0.0921±0.0097*#	0.1018±0.0070^{o}
W80	0.0991±0.0119	0.1148±0.0128*	0.1143±0.0137*^{ab}	0.1179±0.0173*^{b}
W45	0.0988±0.0325	0.1155±0.0119*^{b}	0.1156±0.0193*^{ab}	0.1185±0.0175*^{b}

Maximal efforts training with loads: 10% BW – group M10, 5% BW – group M5, 3 min efforts intermittent training with power of 250 W and pedalling rates: 80 rpm – group W80 and 45 rpm – group W45;
#-averages differ significantly between 4 and 5, 6 measurement, °-averages differ crucially between 5 and 6 recording;
M10 vs. M5, W80, W45, ^{a} – p<0.05, M5 vs. W80, W45, ^{b} – p<0.05

Table 3
Average values (±SD) of the highest powers [W] accomplished by applied load during the force-velocity and power-velocity characteristics determination as well as the significance of differences between averages measured before the research (0) and following ones: (1-4) – during 4 weeks of training; (5-6) – 2 weeks after training period (*-p<0.05)

Load	Group	0	1	2	3	4	5	6
2.5	M10	383.9 ±45.2	377.3 ±41.6	378.9 ±50.6	378.1 ±44.7	372.0 ±53.2	395.0# ±38.1	374.0° ±60.2
	M5	374.1 ±57.2	384.5 ±60.4	386.1 ±60.9	391.2* ±55.7	377.5 ±54.6	399.8*# ±53.5	381.9° ±54.9
	W80	383.2 ±57.3	378.3 ±57.9	382.6 ±57.6	383.2 ±52.0	386.5 ±57.2	376.0 ±64.0	373.7# ±57.5
	W45	382.0 ±46.0	374.6 ±45.6	379.8 ±46.4	380.8 ±48.1	382.3 ±48.4	374.3 ±45.9	370.0*# ±48.4
5.0	M10	670.6 ±92.1	678.0 ±86.8	655.3* ±95.4	664.8* ±103.7	657.9* ±97.5	700.3*# ±91.8	669.7° ±96.9
	M5	669.7 ±105.2	684.2 ±105.6	670.2 ±100.9	675.9 ±102.0	674.9 ±92.6	706.9*# ±102.1	672.8° ±92.7
	W80	692.3 ±109.0	677.7 ±113.7	688.5 ±103.6	696.6 ±82.3	687.6 ±97.6	672.7 ±104.0	662.2# ±99.5
	W45	681.0 ±91.2	670.9 ±82.4	667.1 ±89.7	659.1 ±89.0	691.1 ±92.7	676.1 ±90.1	650.4*# ±92.3
7.5	M10	850.8 ±132.7	859.4 ±123.1	842.8 ±124.3	838.9 ±123.0	849.7 ±135.6	886.6*# ±114.2	844.7° ±150.3
	M5	848.4 ±135.3	844.6 ±120.8	851.6 ±137.3	836.2 ±118.5	871.4 ±122.7	891.9* ±112.2	869.9 ±120.7
	W80	892.6 ±138.1	860.0* 152.1	872.9 ±125.3	874.2 ±135.1	900.1 ±125.9	876.0 ±128.8	856.2# ±140.9
	W45	868.5 ±102.9	871.2 ±110.0	867.8 ±105.1	870.4 ±107.2	900.1* ±115.2	870.4# ±116.3	852.5# ±112.4

Maximal efforts training with loads: 10% BW – group M10, 5% BW – group M5, 3 min efforts intermittent training with power of 250 W and pedalling rates: 80 rpm – group W80 and 45 rpm – group W45.
- averages differ significantly between 4 and 5, 6 measurement, ° - averages differ crucially between 5 and 6 recording; load [% BW]

Table 4
Average values (±SD) of the highest powers [W] accomplished by applied load during the force-velocity and power-velocity characteristics determination, maximal power (Max) as well as the significance of differences between averages measured before the research (0) and following ones: (1-4) – during 4 weeks of training; (5-6) – 2 weeks after training period (*-p<0.05)

Load	Group	0	1	2	3	4	5	6
10.0	M10	944.8 ±142.5	954.3 ±128.6	940.2 ±138.7	957.1 ±144.8	951.9 ±144.7	977.2*# ±130.9	955.3 ±154.9
	M5	943.8 ±157.8	919.1 ±142.2	945.9 ±150.8	922.2 ±133.5	973.3 ±133.8	977.5* ±141.6	970.1 ±146.7
	W80	959.0 ±175.0	949.6 ±145.6	982.8 ±130.2	987.9 ±140.7	1009.5* ±141.3	978.0 ±153.9	990.5 ±151.9
	W45	972.8 ±135.5	956.3 ±105.8	963.9 ±112.4	967.4 ±145.2	1029.3* ±128.7	982.9# ±113.6	978.7# ±133.7
12.5	M10	944.7 ±130.3	989.1 ±155.5	998.5* ±131.9	999.6* ±151.4	1001.6* ±146.5	1036.9* ±154.8	1001.8* ±145.7
	M5	943.4 ±160.3	916.3 ±168.2	984.9 ±172.7	924.0 ±177.5	983.5 ±163.7	982.9 ±194.8	976.1 ±171.6
	W80	942.2 ±161.4	977.6 ±192.9	1000.8 ±151.9	1003.3 ±129.7	1069.9* ±143.1	1021.2* ±146.4	1032.2* ±180.7
	W45	973.4 ±132.9	962.2 ±134.2	992.1 ±123.5	1003.9 ±172.9	1069.1* ±148.4	1036.1 ±128.7	1019.2 ±134.3
Max	M10	974.7 ±138.2	1005.0 ±156.7	1012.7* ±141.0	1006.5 ±154.1	1007.6 ±147.5	1040.8* ±155.3	1015.8* ±159.4
	M5	973.9 ±154.5	967.5 ±158.0	984.5 ±157.7	956.0 ±160.5	1009.0* ±151.4	1031.8* ±174.8	999.1 ±155.7
	W80	1020.3 ±160.1	1004.7 ±171.4	1008.4 ±138.0	1022.9 ±142.8	1074.3* ±142.7	1029.6 ±147.9	1051.4 ±170.1
	W45	1017.4 ±123.7	1000.9 ±109.8	1002.5 ±123.5	1019.3 ±162.5	1077.7* ±139.6	1047.1 ±131.6	1032.7*# 133.6

Maximal efforts training with loads: 10% BW – group M10, 5% BW – group M5, 3 min efforts intermittent training with power of 250 W and pedalling rates: 80 rpm – group W80 and 45 rpm – group W45.
- averages differ significantly between 4 and 5, 6 measurement; load [% BW]

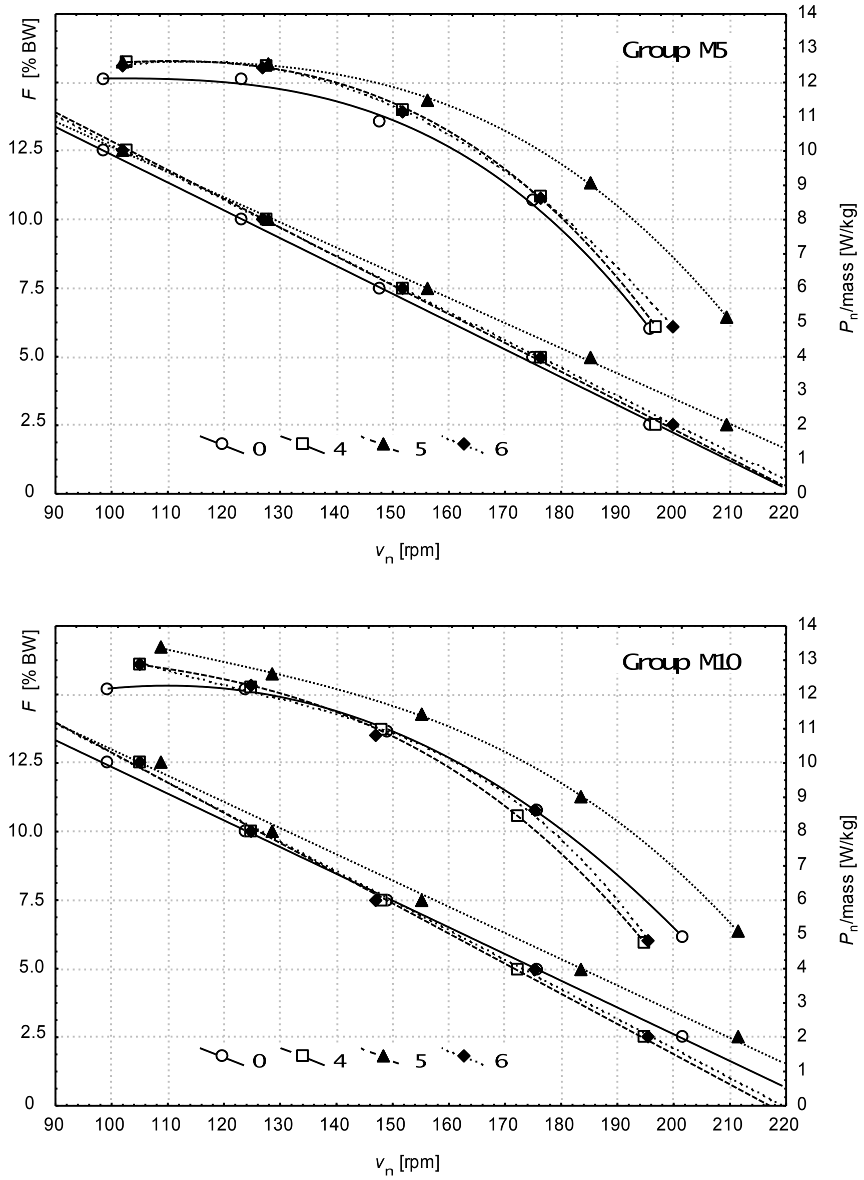

Fig. 1
F-v (bottom) and *P-v* (upper) characteristics attained by groups M5 and M10 before the research (0), after 4 weeks of practice (4); after the 1st week from testing (5) and in 2 week from the research finish (6)

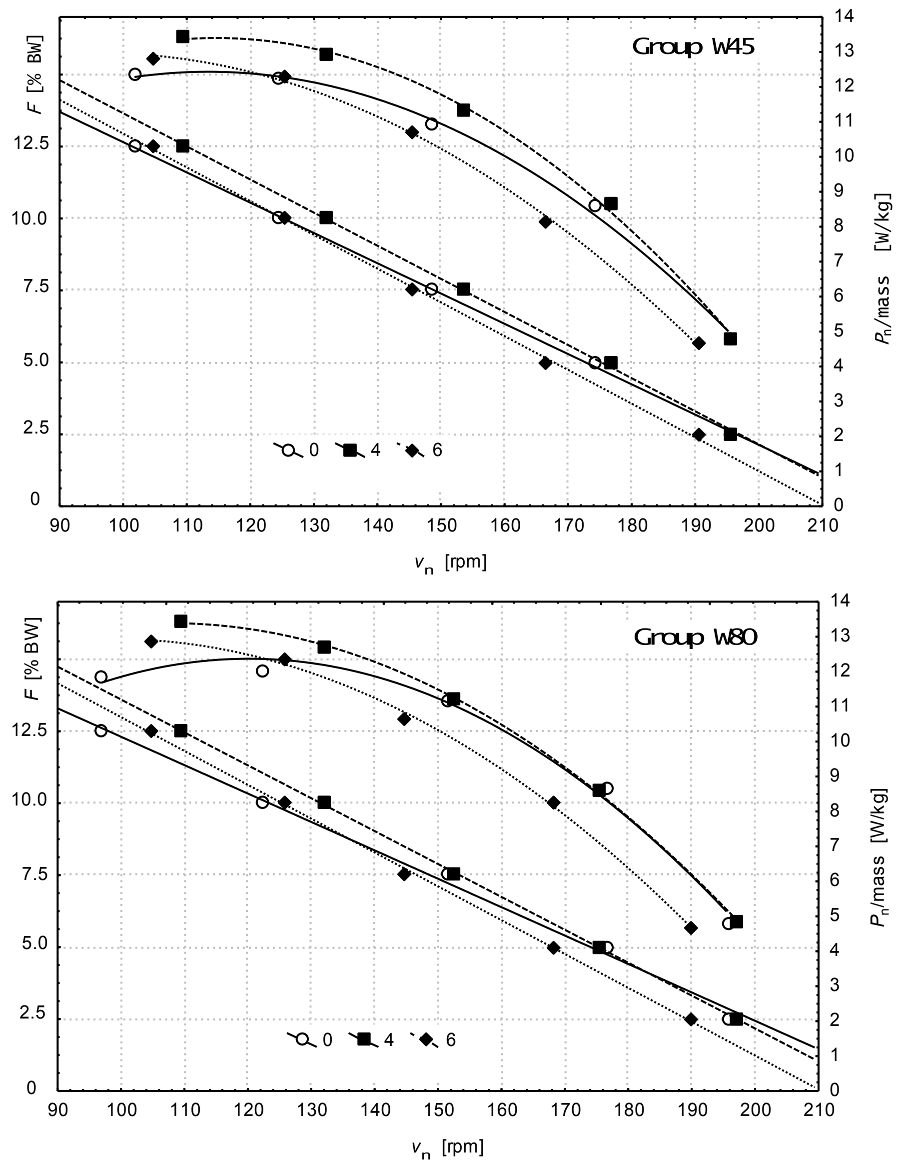

Fig. 2
F-v (bottom) and *P-v* (upper) characteristics obtained by group W45 and W80 before the experiment (0); after 4 week training (4) and in 2 weeks from testing (6)

groups M10, M5 and W80, W45 after the 1st week from the experiment as well as between M5 and W80, W45 after the 2nd week from the test. The highest powers averages produced by applied load (P_n) are presented in Tables 3 and 4. Group M5 showed concurrent increase of *F-v* and *P-v* characteristics while exercises with loads from 2.5 to 12.5% BW in 4 weeks of training (Fig. 1). The most significant P_n changes were noted in the 1st week from trainings (7.4% for load equalling 2.5% BW, 6.0% for 5.0% BW, 5.8% for 7.5% BW, 4.2% for 10.0% BW and 3.9% for 12.5% BW - insignificant). Group M10 displayed after 4 weeks of training the turn in *F-v* and *P-v* curves as regards load 7.5% BW. The characteristics change was elicited by the power lowering: about -3.3% for load of 2.5% BW and -2.0% for 5% BW as well as by its growth: around 0.8% for load of 10.0% BW and 6.1% ($p<0.05$) for 12.5% BW. The largest power changes were observed in the 1st week after exercises by the load equal 2.5% BW for 3.2%, by 5.0% BW for 4.5% ($p<0.05$), by 7.5% BW for 4.7% ($p<0.05$), by 10.0% BW for 3.8% ($p<0.05$) and by 12.5% BW for 10.1% ($p<0.05$). For loads from 2.5 to 10% BW simultaneous displacement of *F-v* and *P-v* relationships curves were recorded. Some important decrease of power considering loads of 2.5 to 10.0% BW was noticed after 2 weeks from testing (in relation to the measurement taken after the 1st week from tests) and *F-v* and *P-v* curves rout overlapped with this obtained after 4 weeks training. The 3 min cycle ergometer training with 250 W power realised by group W45 elicited significant growth of power by loads equal: 7.5%, 10.0% and 12.5% BW for 3.7%, 6.3% and 12.0% respectively (Fig. 2). After the trainings ending the downwards movement of *F-v* curve took place although, only for 5% BW the power loos was important. The significant growth of power occurred under the influence of training with 80 rpm pedalling rate by the load equal 10.0 and 12.5% BW for 6.5 and 15.5% respectively.

Discussion

The dependence between produced power and the pace of shortening of contractile elements is a fundamental characteristic of muscles [11,12]. In the in vitro examinations the maximal power was produced by the optimal velocity and force and the force-velocity (*F-v*) relationship was hyperbolic. In the in vitro research conducted during exercises involving muscles of one joint [6,25,28] or group of joints [4,7,14,27] the *F-v* relationship course was in accordance with Hill’s equation (hyperbolic) or linear [4,22]. In the work of Zalewski *et al.* [31] the *F-v* relationship gained on the cycle ergometer was described by hyperbole and line for efforts performed with upper and lower limbs. The force-velocity relationship obtained by lower limbs exercise was described in this work linearly. It is coherent with other authors results [4,31]. In the work of Vandewalle *et al.* [29] *F-v* characteristics were determined on the cycle ergometer for male and female athletes of various sport disciplines. Linear dependence was found between force and velocity in the range of 100-200 rpm. Short distance runners had bigger values of v_o and P_{max} than athletes practicing endurance disciplines. In papers of Hamar *et al.* [9] and Hamar [10] variations of *F*-v curve in athletes of different sport disciplines were observed. In researches of Buśko and Wit [2] karate athletes produced larger power by smaller loads and higher velocities in comparison to rowers who displayed larger power by heavy loads and slower velocities. Significant differences were stated between groups for the simple force-velocity relationship direction coefficients what confirmed variations of force-velocity curve courses in karate athletes and rowers and might have been elicited by disciplines differences as well as training methods. Crucial changes of force-velocity relationship simple regression direction coefficients observed in this study show that the cycle ergometer training effects the *F-v* relationship route. The intensity of training (maximal or/and submaximal) influence the *F-v* characteristic direction coefficients change what is confirmed by coefficients values obtained after 4 week training and further changes after the 1st week from testing (differences between groups M5, M10 and W45,W80). Next, after the comparison of data reached in the field of similar efforts (M5 vs. M10 and W45 vs. W80) there can be stated that the pedalling rate (high or low) does not influence significantly the simple force-velocity direction coefficient values. After training changes of the simple force-velocity direction coefficient values suggest that the power growth occurred in groups M10, W45 and W80 through the enlargement of force and in group M5 through the velocity increase.

In the accessible references, the influence of various trainings performed with large and small velocity on *F-v* and *P-v* characteristics was studied through: classic form force trainings (weight); using training devices (isokinetic and non-isokinetic cycle ergometers). Force training containing of exercises performed with large load and small velocity improved the final course of *F-v* curve (large force, low velocity) and not the part describing high velocities [1,8,15,24]. However, training with large velocity and small load improved results on the whole curve’s route [8,24] or enlarged the force and power as considering motions performed with high rate [1,15,24]. Basing on data described by Kaneki *et al.* [16], Moritani *et al.* [23], Moss *et al.* [24] and Wilson *et al.* [30] there can be stated that the force training conducted with load equal around 30-40% of maximal load develops power and training with load of 80-100% - force. Results obtained during strength practice may be compared with outcomes gained during isokinetic exercises where high and low velocity was applied. In papers of Cole *et al.* [3] and Ewing *et al.* [5] the isokinetic exercises performed with high velocity improved the power and torque peak by large rates and performed with high velocity made better values of measured amounts only in the field of small paces. In studies of Mannion *et al.* [20,21] trainings performed with high and low velocity did not cause crucial differences between groups in all measured quantities. The present research showed the simultaneous rise of *F-v* and *P-v* characteristics in group M5 after 4 weeks of training in the whole loads range from 2.5 to 12.5% BW. The most important P_n changes were noted in the 1st week after the experiment for loads from 2.5 to 10.0% BW. Students participating in group M5 improved most efficiently the power production in the sphere of large velocities and small forces. Characteristics course was parallel after 2 weeks from trainings to the route observed before the experiment what proves the diminishing of pedalling rate for all loads (for 2.5% BW significant lowering – $p<0.05$). Obtained results are in accordance with the thesis of Häkkinen [8] that the training performed with high and low force betters power in the whole *F-v* and *P*-v characteristics. Immediately after 4 weeks of training the above characteristics courses curves turned according to point 7.5% BW for group M10. The most significant changes of power were observed in the 1st week from trainings by loads from 5.0% to 12.5% BW. For results attained for loads from 2.5 to 10% BW the parallel movement of *F-v* and *P-v* characteristics curves occurred in relation to diagrams marked before the study. After 2 weeks from trainings the significant decrease of produced power was observed (in relation to the previous week) in the range of loads from 2.5% to 10.0% BW and *F-v* and *P-v* characteristics course overlapped with this achieved after 4 week training. Assuming that this research training realised in maximal efforts with 5% BW corresponds to 40% of maximal load (load by which examined subject was not able to perform the trial during *F*-v and *P-v* characteristic determination was accepted as maximal) and with 10% BW to 80% maximal load than acquired results for *F-v* and *P-v* relationships are coherent with outcomes of Kaneka *et al.* [16], Moritani *et al.* [23], Moss *et al.* [24] and Wilson *et al*. [30] who stated that the force training conducted with load equal 30-40% of its maximal value develops power and at the level of 80-100% load - bettered is the force. The lack of differences between groups M5 and M10 is in accordance with results of Mannion *et al.* [20,21]. Analysing the *F-v* and *P-v* characteristic attained in this research after trainings with the same intensity and differed only by the pedalling rate (high and low velocity) the following fact was noted: 3 min exercises on the cycle ergometer with average power of 250 W and pedalling rate 45 rpm and 80 rpm effected in the growth of power. In group W45 power grew significantly for about 3.7%, 6.3% and 12.0% by load of 7.5%, 10.0% and 12.5% BW respectively. After the training finish the *F-v* line moved downwards what was a result of the pedalling rate lowering and it considered all test loads. However, only for 5% BW this fall was crucial. The significant grow of power was noted under the influence of 80 rpm pedalling training and loads of 10.0 and 12.5% BW for 6.5% and 15.5% respectively. Bigger decrease of power was noticed in group W80 in the range of higher pedalling rates after 4 week training. The growth of power after 4 week training in both groups only in the field of small pedalling velocities (load 10.0 and 12.5% BW) and significant drop of power in both groups during high velocity trials (load equal 2.5 and 5.0% BW) is in the contradiction with the thesis of Häkkinen [8] that the training performed with high velocities and small force (group W80) improves the power in all *F-v* and *P-v* characteristics. Unless, the above statement regards maximal efforts and cannot be applied for 3 min efforts with average power of 250 W. Present study results are in disagreement also with reports of Bell *et al.* [1]; Kanehis and Miyashita [15] and Moss *et al.* [24] who stated that the low velocity training betters the power in motions performed with small pace and high velocity practice improves motion power in the range of high velocities. Values of produced power did not differ significantly in all trials of both groups. It is the prove that after training power changes did not depend on the pedalling rate. It is coherent with outcomes of Mannion *et al.* [20,21] where the isokinetic practice performed with high and low velocity did not elicit crucial differences among groups.

Worth noticing are the following points: 1) submaximal trainings with the average power equal 250 W caused bigger power increase by loads of 10.0 and 12.5% BW than maximal effort trainings. Next, the sprint practice elicited higher power growth by loads of 2.5, 5.0 and 7.5% BW in relation to submaximal trainings; 2) *F-v* relationship line coefficients changes suggested that submaximal practice with power of 250 W elicited the power increase through the improvement of force alike in maximal efforts with BW equal 10%. If we accept that 250 W submaximal efforts training presents 30-80% of maximal load than the power growth obtained in this research is in agreement with results of Moss *et al.* [24] who did not find significant differences of maximal power produced after 9 week force training conducted with maximal velocity and load equal 35 and 90% of maximal load. The above thesis is supported also by outcomes of Moritani *et al.* [23] and Wilson *et al.* [30] who claimed that exercises performed with load equal 30-40% of maximal load develop power and fitness in the best possible way.

Getting into conclusion, the highest power growth measured in *F-v* and *P-v* characteristics was observed after the 1st week from the whole training which was realised through maximal efforts in groups M5 and M10 as well as immediately after the 4 week practice of 3 min efforts with the average power equal 250 W in groups W45 and W80. The highest after training changes of power output in groups M5 and M10 were noted by loads of 2.5, 5.0 and 7.5% BW and in groups W45 and W80 by loads equal 10.0 and 12.5% BW. The lack of significant differences between groups suggest that the pedalling rate and efforts intensity have no influence on the after effort power developed during *F-v* and *P-v* characteristic determination (especially groups W45 and W80). The trainings intensity effects the force-velocity simple relationship direction coefficients value.

References

1. Bell G.J., S.R.Petersen, H.A.Quinney, H.A.Wenger (1989) The effect of velocity-specific strength training on peak torque and anaerobic rowing power. *J.Sports Sci.* 7:205-214

2. Buśko K., B.Wit (2002) Force-velocity relationship of lower extremity muscles of karate athletes and rowers. Biol. Sport 19(4): 373-384.

3. Coyle E.F., D.C.Feiring, T.C.Rotkis, R.W.Cote 3rd, F.B.Roby, W.Lee, J.H.Wilmore (1981) Specificity of power improvements through slow and fast isokinetic training. *J.Appl.Physiol.* 51:1437-1442

4. Davies C.T.M., J.Wemyss-Holden, K.Young (1984) Measurement of short term power output: Comparison between cycling and jumping. *Ergonomics* 27:285-296

5. Ewing J.L. Jr, D.R.Wolfe, M.A.Rogers, M.L.Amundson, G.A.Stull (1990) Effects of velocity of isokinetic training on strength, power, and quadriceps muscle fibre characteristics. *Eur.J.Appl.Physiol.* 61:159-162

6. Ferri A., G.Scaglioni, L.Ciuffreda, P.Capodaglio, J.Van Hoecke, M.V.Narici (2000) Muscle strength and power changes following a 16-week resistance training in the elderly. In: J.Avela, P.V.Komi, J.J.Komulainen (eds.) Proceedings of the 5th Annual Congress of the European Collage of Sport Science, Jyvaskyla, Finland, pp. 261

7. Häkinnen K., P.V.Komi, M.Alén, H.Kauhanen (1987) EMG, muscle fiber and force production characteristics during a 1 year training period in elite weight lifters. *Eur.J.Appl. Physiol.* 56:419-427

8. Häkkinen K. (2000) Neuromuscular adaptation to strength training in men and women and strength athlete. In: C.P.Lee (ed.) 2nd International Conference on Weightlifting and Strength Training. Ipoh, Malyasia. Pro Muscle, Dept. of Education 2000, pp. 5-9

9. Hamar D., O.Gazovic, P.Schickhofer (1998) A simple system for strength testing and feedback monitoring of weight training. In: K. Häkkinen (Ed.) Conference book,

International Conference on Weightlifting and Strength Training, Lahti, Finland. Printed by Gummeras Printing, Finland, pp. 169-170

10. Hamar D. (1999) Monitorowanie biomechanicznych parametrów ruchu podczas ćwiczeń ze sztangą. *Sport Wyczyn.* 1-2:36-45 (in Polish, English abstract)

11. Hill A.V. (1938) The heat of shortening and dynamic constants of muscle. Proc. R. Soc. London Ser. B 126:136-195

12. Hill A.V. (1964) The efficiency of mechanical power development during muscular shortening and its relation to load. Proc. R. Soc. London Ser. B 159:319-325

13. Inbar O., O.Bar-Or, J.S.Skinner (1996) The Wingate Anaerobic Test. Human Kinetic Publisher, Champaign, IL

14. Jaskólska A., P.Goossens, B.Veemstra, A.Jaskólski, S.Skinner (1999) Comparison of treadmill and cycle ergometer measurements of force-velocity relationships and power output. *Int.J.Sports Med.* 20:192-197

15. Kanehisa H., M.Miyashita (1983) Specifity of velocity in strength training. *Eur.J. Appl.Physiol.* 52:104-106

16. Kaneko M., T.Fuchimoto, H.Toji, K.Suei (1983) Training effect of different loads on the force-velocity relationship and mechanical power output in human muscle. *Scand.J. Sports Sci.* 5:50-55

17. Linossier M.-T., C,Denis, D.Dormois, A.Geyssant, J.R.Lacour (1993) Ergometric and metabolic adaptation to a 5-s sprint training programme. *Eur.J.Appl.Physiol.* 67: 408-414

18. Linossier M.-T., D.Dormois, A.Geyssant, C.Denis (1997) Performance and fibre characteristics of human skeletal muscle during short sprint training and detraining on a cycle ergometer. *Eur.J.Appl.Physiol.* 75:491-498

19. Linossier M.-T., D.Dormois, C.Perier, J.Frey, A.Geyssant, C.Denis (1997) Enzyme adaptations of human skeletal muscle during bicycle short-sprint training and detraining. *Acta Physiol.Scand.* 161:439-445

20. Mannion A.F., P.M.Jakeman, P.L.Willan (1992) Effects of isokinetic training of the knee extensors on isometric strength and peak power output during cycling. *Eur.J.Appl. Physiol.* 65:370-375

21. Mannion A.F., P.M.Jakeman, P.L.Willan (1994) Effects of isokinetic training of the knee extensors on high-intensity exercise performance and skeletal muscle buffering. *Eur.J. Appl.Physiol.* 68:356-361

22. McCartney N., G.J.F.Heigenhauser, N.L.Jones (1983) Power output and fatigue of muscle in maximal cycling exercise. *J.Appl.Physiol.* 55:218-224

23. Moritani T., M.Muro, K.Ishida, S.Taguchi (1987) Electrophysiological analyses of the effects of muscle power training. *Res.J.Phys.Ed.* 1:23-32

24. Moss B.M., P.E.Refsnes, A.Abildgaard, K.Nicolaysen, J.Jensen (1997) Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships. *Eur.J.Appl.Physiol.* 75:193-199

25. Perrine J.J., V.R.Edgerton (1978) Muscle force-velocity and power-velocity relationship under isokinetic loading. *Med.Sci.Sports* 10:159-166

26. Rutherford O.M., D.A.Jones (1986) The role of learning and co-ordination in strength training. *Eur.J.Appl.Physiol.* 55:100-105

27. Sargeant A.J., E.Hoinville, A.Young (1981) Maximum leg force and power output during short-term dynamic exercise. *J.Appl.Physiol.* 51:1175-1182

28. Tihanyi J., P.Apor, G.Fekete (1982) Force-velocity-power characteristics and fiber composition in human knee extensor muscles. *Eur.J.Appl.Physiol.* 48:331-343

29. Vandewalle H., G.Peres, J.Heller, J.Panel, H.Monod (1987) Force-velocity relationship and maximal power on a cycle-ergometer. *Eur.J.Appl.Physiol.* 56:650-656

30. Wilson G.J., R.U.Newton, A.J.Murphy, B.J.Humphries (1993) The optimal training load for the development of dynamic athletic performance. *Med.Sci.Sports Exerc.* 25: 1279-1286

31. Zalewski J., K.Zalewska, D.Cylka, A.Jaskólski, A.Jaskólska, A.Kowalczykowski, J.Krawczak (1994) Zależność między siłą a prędkością ruchu podczas pracy kończynami górnymi lub dolnymi. *Wychow.Fiz.Sport* 1:43-51 (in Polish, English abstract)

Accepted for publication 30.09.2003