Biology of Sport, Vol. 25 N^{o}3, 2008

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CHANGES OF MUSCLE TORQUE AFTER SPRINT AND ENDURANCE TRAINING PERFORMED ON THE CYCLE ERGOMETER

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Abstract. The aim of this work was the specification of the influence of the sprint and endurance training performed on the cycle ergometer on changes of muscle torque. Forty three students of the Academy of Physical Education in Warsaw took part in the study. They were divided into 4 groups and performing the cycle ergometer training consisting of 5 intermittent efforts (2 min break): S10 group- the sprint training (maximal efforts performed with the 10% body weight load); S5 group- the sprint training (maximal efforts conducted with 5% body weight load); W80 group – endurance training (the effort power equal 250 W, single – 3 min effort equal 45 kJ, the pedalling rate – 80 rpm, load 31,0 N appended on the cycle ergometer scale); W45 group – endurance training (the effort power equal 250 W, single – 3 min effort equal 45 kJ, the pedalling rate 45 rpm, load 55.0 N appended on the cycle ergometer scale). The four - week sprint training conducted on the cycle ergometer elicited the increase of the torque of the hip extensors and flexors in S10 and S5 group; extensors of the knee joint in S5 group and plantar flexors in S10 group. The four week endurance training carried out on the cycle ergometer caused the increase of the torque of hip extensors in groups W80 and W45, extensors of the knee joint and plantar flexors in group W45 as well the lowering of the torque of hip flexors in W80 and W45 group and the knee joint flexors in all groups. The significant increase of the sum of the 5 examined muscle groups torque was observed after the sprint training only. Some significant differences between the sprint and endurance training considered hip flexors and the sum of 5 examined muscle groups torque. The endurance training elicited the significant decrease of an hip flexors-to-extensors index value in groups W80 and W45 and of the knee joint in group W45.

(Biol.Sport 25:275-294, 2008)

Key words: Muscle torque - Sprint training - Cycle ergometer - Endurance training

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Introduction

The power training causes a muscle hypertrophy and the increase of strength [19,24,37] with small or without the aerobic capacity growth [18,41]. As a contrary, the small resistance training with periodically performed endurance efforts e.g.: running, swimming or cycling effects in growth of the VO_{2max} and the ability of long lasting exercises performance without increase of the strength or muscles hypertrophy [1,2]. It is believed that the mixed training e.g.: strength training + endurance training t [24] or sprint training + endurance training [34] causes smaller changes of strength and power as well of the physical adaptation to effort in comparison to the single training such as the strength training, the speed training or the endurance training done solely. There are few papers in references considering the influence of the sprint or intermittent training carried out on the cycle ergometer on the increase of the muscle torque. Changes of the isometric force after the singular cycle ergometer ride were examined most frequently [3,4,26]. The fact that the 8 week sprint track training effected in growths of the isometric strength and the CMJ jump was noticed only in the work of Thorstensson *et al*. [36]. Additionally, in a work of Fidelus *et al*. [17] the muscle torque growth and the power decrease during maximal takes off on the skids after 4 week speed training on the cycle ergometer was shown.

The aim of this paper was the determination of the influence of the sprint and endurance training performed on the cycle ergometer on muscles torque.

Materials and Methods

The study was conducted on 43 non-athletes, students of APE. They were divided into 4 subgroups: two performing the sprint training (S10, n=9 and S5, n=11)and two performing the endurance training (W80, n=11 and W45, n=12). Examined subjects characteristics are presented in Table 1. Groups did not differ significantly as considering an anthropological features.

The research was accepted by the Senate Scientific Research Board of Ethics by the Academy of Physical Education in Warsaw. Students were informed about the research aim and methodology of its performance. They acknowledged the possibility of resignation in every moment of the study. Examined subjects accepted the above conditions in written form. All the measurements were taken before noon.

Table 1
Examined groups characteristics (mean ±SD)

Groups	Age (years)	Body height (cm)	Body mass (kg)
S10 (n=9)	22.2±1.8	178.1±6.5	77.8±10.5
S5 (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

S10 - the sprint training (load - 10% BW); S5 - the sprint training (load - 5% BW); W80 - the endurance training (80 rpm); W45 - the endurance training (45 rpm)

The experiment course: Examined subjects have acquainted with all measurements methods and performed the initial Wingate test on the cycle ergometer (Monark 824E, Sweden) according to the standard methodology described in the work of Bar-Or [2] before the experiment beginning.

All groups' participants were performing, during 4 weeks, 4 times a week, sprint or endurance tests on the Monark 824E cycle ergometer combined with the computer equipped with the MCE v. 4.0 programme (JBA Zb. Staniak, Poland). The test and sprint trainings were done sitting, without standing on pedals and riding began from the motionless position. Feet were fastened to pedals with strips. The experiment participants were encouraged to gaining the maximal speed as fast as they were able and keeping it until the end of the test. In a case of the endurance training the 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 S10 (sprint training) – 5 maximal efforts: first – 100% of work determined in the Wingate test (19.36±2.58 kJ); other four – 50% of the above work (loads equal 10% of the body weight). The interval between trainings equalled 2 min.
- group S5 (sprint training) – 5 maximal efforts: first – 100% of work determined in the Wingate test (19.16±2.30 kJ); other four – 50% of the above work (loads equal 5% of the body weight). The interval between trainings equalled 2 min.

- group W80 (endurance training) – 5 lasting for 3 min efforts with the power of 250 W and work of about 45 kJ (pedalling rate 80 rpm, load 31,0 N appended on the cycle ergometer scale). The interval between trainings equalled 2 min.
- group W45 (endurance training) – 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.

Examined subjects did not perform other trainings and had no additional food supplementation during the whole study.

The control measurements of the right lower limb muscles torque were taken every Monday before tests beginning (0), for four weeks of trainings (1-2) and for two weeks after the research (5-6).

Muscle torque measurement: The measurement of the hip and knee joint flexors and extensors torque was performed on a special stand. The knee muscles torque measurement was taken in a sitting and the hip in a frontal recumbent position. The examined subject was stabilized with strips in both measurement positions. Measurements were taken for a 90º angle in both hip and knee joints. The plantar flexors torque measurement was taken on the special stand as well [43]. The examined student sat in an arm-chair in position which enabled having the same angles (90º) in the hip, knee and ancle-tibial joints. The lower limb was stabilized with an iron bangle. Results of all measurements were read by a digital index, scaled in torque units. The flexors-to-extensors index was calculated basing on reached muscles torque values [38].

The analysis of variance ANOVA was used to the results comparison. The significance of differences between averages was evaluated post hoc – using the LSD test (least significant difference test). The degree of dependence between the muscles torque (MT) and the body mass was evaluated basing on a Pearson's correlation coefficients. All calculations were conducted using a STATISTICA^{TM} programme (v. 5.5, StatSoft, USA).

Results

The hip extensors (HE) torque values grew significantly in S10 group from 331.7±64.3 to 356.2±77.0 N·m after 2 weeks from the test finish and in group S5 from 363.0±59.2 to 388.8±72.4 N·m after 4 weeks of training (Table 2).

Table 2
Average values (±SD) of the hip and knee joint extensors and flexors torque (HE, HF, KE, KF respectively) and the significance of the average differences of measurements taken before the experiment (0) and following ones: (1-4) – four week training; (5-6) – two weeks after trainings (*- p<0.05)

Variable		0	1	2	3	4	5	6
	S10	331.7	343.5	347.3	337.9	353.6*	350.2	356.2*
		±64.3	±89.0	±80.2	±86.8	±90.5	±93.2	±77.0
	S5	363.0	362.9	363.9	369.0	388.8*	373.2	368.0
HE		±59.2	±64.0	±54.4	±63.1	±72.4	±65.5	±61.5
[N·m]	W80	359.2	332.2	324.0*	361.2	370.9	352.8	340.1
		±94.6	±72.3	±60.9	±59.8	±51.8	±60.5	±66.3
	W45	358.8	330.5*	341.7	360.8	376.5	360.9	351.1[#]
		±52.3	±55.5	±52.3	±72.6	±53.7	±70.4	±64.9
	S10	160.4	161.2	175.2*	173.2*	171.8	176.9*	175.8*
		±31.7	±21.3	±30.3	±25.9	±16.5	±29.7	±24.5
	S5	161.6	165.9	169.1	166.0	166.5	173.2	177.6*
HF		±29.4	±33.7	±27.0	±25.0	±30.1	±25.6	±27.9
[N·m]	W80	171.4	168.6	155.4*	150.5*[a]	143.9*[ab]	141.5*[ab]	146.8*[b]
		±27.2	±27.7	±22.8	±17.1	±15.7	±19.7	±35.9
	W45	172.7	170.9	164.5	157.5	154.4*	153.7*[a]	164.9
		±23.2	±26.3	±21.3	±20.5	±28.1	±18.7	±46.1
	S10	225.3	223.6	218.7	223.4	229.8	229.3	229.3
		±39.4	±45.5	±43.0	±46.0	±51.8	±49.6	±46.1
	S5	218.9	216.5	223.7	227.7	233.3*	232.7*	232.3*
KE		±43.1	±37.6	±41.7	±34.7	±42.2	±46.4	±44.8
[N·m]	W80	252.0	255.1[b]	250.3	244.7	238.6	233.0	256.0
		±49.9	±26.8	±34.4	±34.6	±27.9	±39.3	±39.1
	W45	231.3	229.4	230.9	232.8	242.6	243.3	247.4
		±40.9	±30.9	±37.4	±40.8	±26.7	±25.2	±29.2
	S10	145.1	141.5	141.0	140.0	143.6	141.9	142.6
		±32.7	±36.6	±35.3	±37.5	±30.2	±29.4	±29.0
	S5	144.0	147.6	150.0	144.2	148.6	145.6	144.8
KF		±26.3	±28.5	±26.3	±31.6	±31.3	±29.9	±35.2
[N·m]	W80	151.0	148.2	150.1	150.2	142.5	143.1	144.9
		±31.7	±30.8	±31.1	±28.9	±27.2	±35.4	±35.2
	W45	148.5	150.7	142.8	144.0	137.3	138.8	140.5
		±33.7	±31.3	±25.2	±25.4	±28.7	±27.3	±23.8

[#]- averages differ significantly between the 4th and 6th measurement; S10 vs. S5, W80, W45, [a]- p<0.05; S5 vs. W80, W45, [b]- p<0.05

The significant decrease of HE was stated in group W80 from 359.2±94.6 to 324.0±60.9 N·m after 2 week training. Next, the insignificant increase of HE was stated in this group after 4 weeks training to 370.9±51.8 N·m. The muscles torque (MT) value decreased again after the whole experiment completion to 340.1±66.3 N·m. The MT decreased in group W45 from 358.8±52.3 to 330.5±55.5 N·m in the 1st week of training. Next, the insignificant growth of the HE value was observed after 4 weeks of training to 376.5±53.7 N·m. The MT value decreased again after the whole test completion to 351.1±64.9 N·m. Significant differences of muscles torque values between groups were not stated. Some significant disagreement between groups S10 and W45, W80 was observed for the percentage changes of muscle torque after the 1st and 2nd week of trainings (Fig. 1)

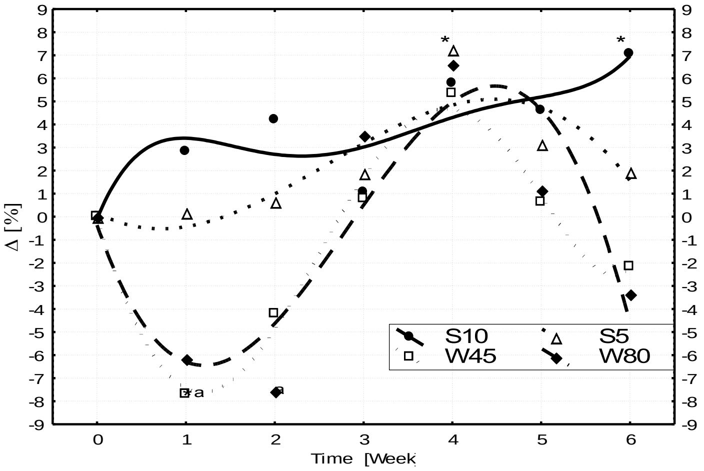

Fig.1
Average values of the hip extensors torque changes (Δ [%]) calculated according to the measurement taken before the test (presented in percents) and the significance of average differences considering the measurement taken before the test (0) and following ones: (1-4) – four week training, (5-6) – a fortnight period after trainings (*- $p<0.05$); (S10 vs. S5, W80, W45, ^{a}- $p<0.05$; S5 vs. W80, W45, ^{b}- $p<0.05$)

The cycle ergometer training caused the significant increase of the hip flexors torque (HF) from 160.4±31.7 to 176.9±29.7 N·m in group S10 during the 1st week after the test completion and from 161,6±29.4 to 177.6±27.9 N·m in group S5 in the 2nd week after the experiment. It caused also the significant decrease of the MT values in groups subjected to the endurance training from 171.4±27.2 to

141.5±19.7 N·m in group W80 and from 172.7±23.2 to 153.7±18.7 N·m in group W45. Significant differences between groups: S10 and W45 were observed as considering HF in the first week after the experiment, W80 and S10, S5 after 4 week training and during 1st and 2nd week after the test completion. Changes of the muscles torque calculated in percents were noticed between groups W80, W45 and S10, S5 after 4 week training and during the 1st and 2nd week after the whole test (Fig. 2).

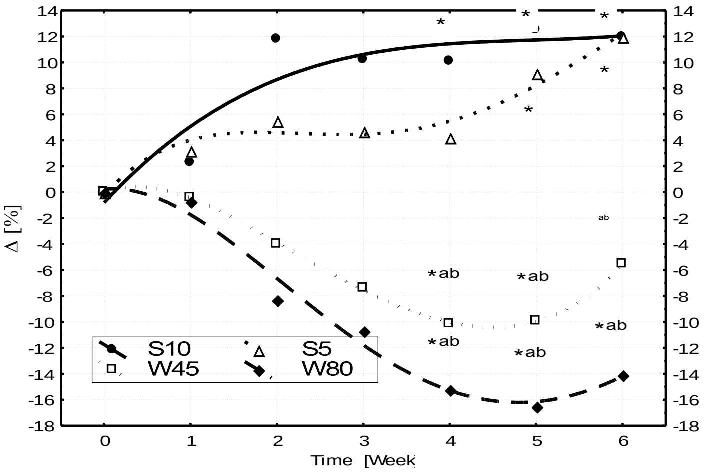

Fig. 2
Average values of the hip flexors torque changes (Δ [%]) calculated according to the measurement taken before the test (presented in %) and the significance of the average differences regarding the measurement collected before the test (0) and following ones: (1-4) - four week training, (5-6) – the fortnight after trainings (*- p<0.05); (S10 vs. S5, W80, W45, ^{a}- p<0.05; S5 vs. W80, W45, ^{b}- p<0.05)

The knee joint extensors torque (KE) changed insignificantly in groups: S10– from 225.3±39.4 to 229.3±46.1 N·m; W80 – from 252.0±49.9 to 238.6±27.9 N·m; W45 – from 231.3±40.9 to 247.4±29.2 N·m. The significant growth of the MT value was observed only in group S5 from 218.9±43.1 to 233.3±42.2 N·m after 4 weeks of training. Significant differences between groups S5 and W80 considered KE in the 2nd week of trainings. As regards the percentage muscle torque, changes were observed in the 1st week after the test completion between groups S5, W45 and W80 (Fig. 3).

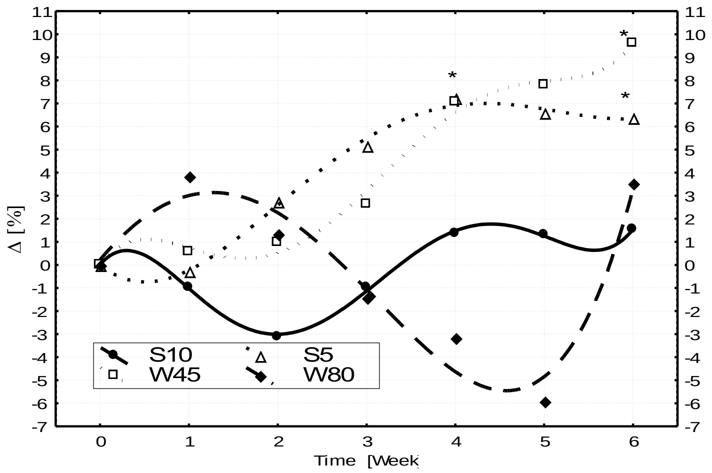

Fig. 3
Average values of the knee joint extensors torque changes (Δ [%]) calculated according to the measurement taken before the experiment (presented in percents) and the significance of average differences between the measurement taken before the test (0) and following ones: (1-4) – four week training, (5-6) – the fortnight after trainings (*- p<0.05)

In the case of the knee joint flexors torque (KF) the significant decrease from 148.5±33.7 to 137.3±28.7 N·m was observed after 4 week training in group W45. The growth of MT to 140.5±23.8 N·m occurred 2 weeks after the test. The cycle ergometer training did not cause significant changes of the knee joint flexors torque in groups S10, S5 and W80.

The plantar flexors (PF) torque value increase significantly in group S10 from 252.0±50.4 to 275.0±65.8 N·m after 4 week training and next, decreased to 258.2±69.2 N·m. The significant growth of MT from 227.2±39.1 to 254.3±53.0 N·m after 4 week training was stated in group W45. This increase maintained until the experiment's end. The cycle ergometer training did not elicit significant changes of the plantar flexors torque in S5 and W80 group. Reached values of the knee joint and plantar flexors torque did not differ significantly between groups throughout the experiment (Fig. 4).

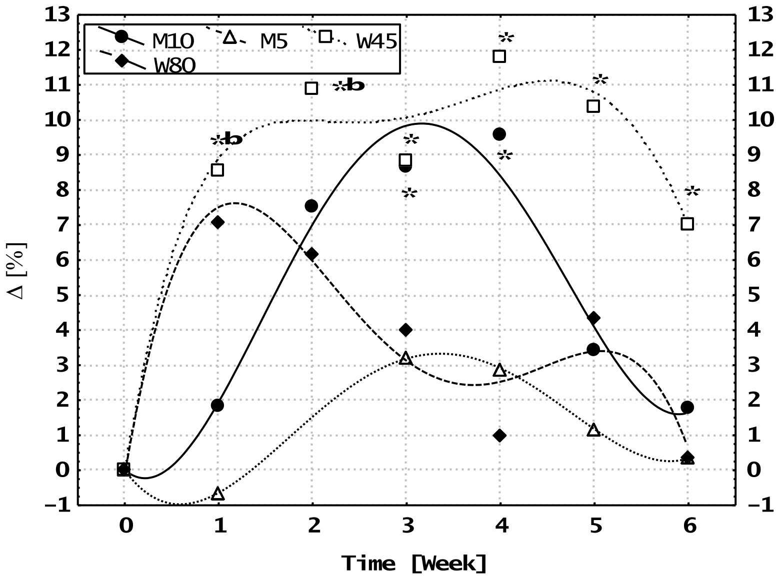

Fig. 4
Average values of the plantar flexors torque changes (Δ [%]) calculated according to the measurement taken before the test (presented in %) and the significance of average differences considering the measurement collected before the test (0) and following ones: (1-4) – four week training, (5-6) – the fortnight after trainings (*- p<0.05; S5 vs. W80, W45, ^{b}- p<0.05)

The sum of 5 examined muscles torque (SUM) increased significantly from 1114.6±197.4 to 1173.7±227.2 N·m in group S10 and from 1155.9±197.7 to 1210.6±173.2 N·m in group S5 after 4 week training. The significant decrease of MT from 1174.5±224.2 to 1120.6±173.2 N·m after 1st week from the training finish was observed in group W80. The insignificant growth from 1138.4±156.3 to 1165.1±148.0 N·m was noticed in group W45. Crucial differences between groups W80 and S10, S5 were observed as considering the percentage changes of MT after 4 weeks of training and after 1st and 2nd week from the experiment (Fig. 5).

The flexors-to-extensors index (FEI) value changed significantly under the influence of training: in group W80 from 0.49±0.06 to 0.40±0.07 for the hip joint; in group W45 from 0.64±0.08 to 0.57±0.11 for the knee joint and from 0.48±0.05 to 0.42±0.09 for the hip joint after 4 week training (Table 3). Some significant differences considering the hip joint were observed between groups S10 and W45, W80 after 4 week training and in the 1st week after the experiment.

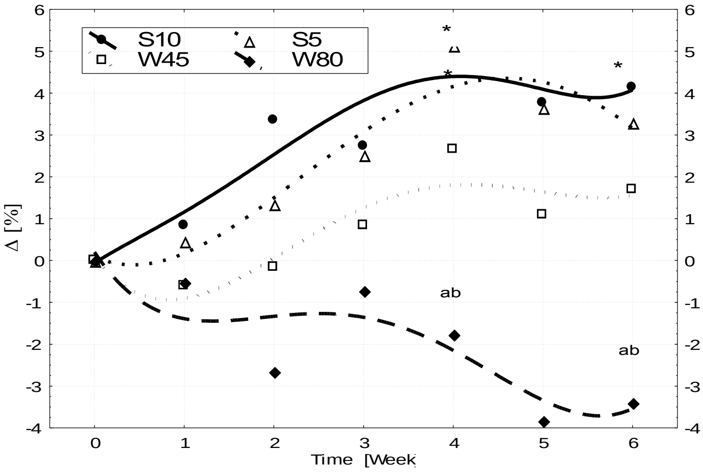

Fig. 5
Average values of changes of 5 examined muscle groups torque (Δ [%]) calculated according to the measurement taken before the experiment (presented in %) and the significance of average differences regarding the measurement acquired before the test (0) and following ones: (1-4) – four weeks of training, (5-6) – two weeks after trainings (*- $p<0.05$); (S10 vs. S5, W80, W45, [a]- $p<0.05$; S5 vs. W80, W45, [b]- $p<0.05$)

Table 3
Average values (±SD) of the plantar flexors torque (PF), sum of 5 examined muscle groups torque (SUM), flexors-to-extensors index (FEI) for the hip (H) and knee (K) joint and the significance of the average differences of measurements taken before the experiment (0) and following ones: (1-4) – four week training; (5-6) – two weeks after trainings (*- $p<0.05$)

Variable	0	1	2	3	4	5	6
S10	252.0	255.2	272.4	274*	275*	263	258.2
	±50.4	±45.8	±68.4	±64.1	±65.8	±75.3	±69.2
S5	268.4	265.4	259.1	273.7	273.4	269.5	269.1

PF		±62.9	±62.5	±46.6	±61.2	±58.1	±65.7	±63.9
[N·m]	W80	240.9	54.0	251.6	246.0	243.9	250.2	243.6
		±53.9	±48.7	±43.0	±38.0	±58.5	±52.7	±65.3
	W45	227.1	246.5*	252.4*	247.7*	254.3*	249.4*	243.6*
		±39.1	±49.1	±56.8	±55.9	±53.0	±44.3	±50.7
	S10	1114.6	1124.9	1154.7*	1148.6	1173.7*	1161.3*	1162.1*
		±197.4	±214.7	±230.6	±241.2	±227.2	±245.7	±220.2
	S5	1155.9	1158.3	1165.8	1180.6	1210.6*	1194.1	1191.7
SUM		±197.7	±186.9	±164.7	±178.2	±191.4	±193.9	±203.3
[N·m]	W80	1174.5	1158.1	1131.4	1152.6	1139.7	1120.6*	1131.4
		±224.2	±167.3	±158.4	±147.2	±136.6	±173.2	±210.9
	W45	1138.4	1128.0	1132.3	1142.7	1165.1	1146.0	1152.5
		±156.3	±147.8	±144.3	±153.6	±148.0	±145.0	±143.3
	S10	0.65	0.64	0.65	0.63	0.64	0.63	0.63
		±0.11	±0.14	±0.13	±0.14	±0.12	±0.10	±0.11
	S5	0.66	0.69	0.68	0.63	0.64	0.63	0.63
FEI$_K$		±0.07	±0.12	±0.11	±0.09	±0.06	±0.06	±0.11
[-]	W80	0.60	0.58[b]	0.60	0.61	0.60	0.61	0.56
		±0.07	±0.11	±0.08	±0.09	±0.08	±0.08	±0.08
	W45	0.64	0.66	0.63	0.64	0.57*	0.57*	0.57*
		±0.08	±0.11	±0.10	±0.15	±0.11	±0.08	±0.09
	S10	0.49	0.48	0.52	0.53	0.50	0.52	0.50
		±0.06	±0.07	±0.10	±0.09	±0.09	±0.10	±0.08
	S5	0.45	0.46	0.47	0.46	0.44	0.47#	0.49
FEI$_H$		±0.05	±0.09	±0.07	±0.09	±0.10	±0.07	±0.07
[-]	W80	0.49	0.52	0.49	0.43[a]	0.40*[a]	0.41*[a]	0.44
		±0.06	±0.12	±0.09	±0.08	±0.07	±0.07	±0.08
	W45	0.48	0.53	0.49	0.45	0.42*[a]	0.44[a]	0.47[#]
		±0.05	±0.09	±0.09	±0.11	±0.09	±0.09	±0.11

[#]- averages differ significantly between the 4th and 6th measurement; S10 vs. S5, W80, W45, [a]- $p<0.05$; S5 vs. W80, W45, [b]- $p<0.05$

Discussion

Sprint and endurance trainings used in our research elicited the growth of torque of hip extensors and flexors and plantar flexors in group S10; hip and knee extensors and flexors in group S5; hip extensors in group W80 as well hip and knee extensors and plantar flexors in group W45. The exception were hip and knee flexors torque in groups W80 and W45. Similar changes after training were noticed between groups as regards: hip extensors (S10 = +5.8%; S5 = +7.3%; W80 = +6.6%; W45 = +5.3%) and plantar flexors (S10 = +9.6%; S5 = +3.2%; W80 = +4.4%; W45 = +11.8%). Somewhat distinct changes were observed as considering: hip flexors (S10 = +12.5%; S5 = +12.0%; W80 = -16.5%; W45 = -10.2%), knee joint extensors (S10 = +1.4%; S5 = +7.2%; W80 = -5.9%; W45 = +7.8%) and knee joint flexors (S10 = -4.0%; S5 = +3.3%; W80 = -5.5%; W45 = -6.6%). Results reached in this experiment are only partly coherent with results obtained by other authors. Hickson [20] stated that 10-week strength training combined with the endurance training gives smaller effects than conducted individually. On the other hand, the endurance work (on the cycle ergometer and running) did not cause changes. Kraemer *et al*. [24] also stated that the combined force and endurance training effects in smaller changes of muscles force and the maximal power measured by the Wingate test in comparison to the individual strength training. The endurance training (running) did not cause changes of the maximal power measured by the Wingate test and of the amount of the maximal load lifted in chosen exercises. This may suggest, according to Craig *et al*. [12], that the endurance training restricts the muscles capacity and disturbs the long lasting cycle of its enlargement. Pauletto [32] believes that the aerobic capacity training influences negatively the strength level increase. In our research, the endurance training performed on the cycle ergometer and measures statically elicited the significant percentage growth of the hip joint extensors, plantar flexors and knee extensors torque only in group W45. The observed lowering of the percentage MT values of the hip and knee joint flexors and knee joint extensors (group W80) confirms the above authors results. Those data imply that the final training result depends on the measured muscles group. In the research of Sleivert *et al.* [34] examined for 14 weeks subjects executed sprint training on the cycle ergometer consisting of 10 and 120 s efforts (group SS) and mixed training (8 week – strength training, 6 weeks – continuation of the strength training + sprint training as in group SS). The sprint training did not cause some significant growth of the isometric and dynamic strength of the knee joint extensors and plantar flexors in both groups (measured by Cybex device). McKenna *et al.* [29] did not stated changes of the quadriceps of thigh maximal isometric strength (unpublished data) after 7 week sprint training on the Monark cycle ergometer (maximal efforts – 30 s long with the load 7.5% BW, performed 3 times a week). On the other hand, Fidelus *et al.* [17] noticed some changes of muscles torque after 4 week sprint training on the cycle ergometer executed 5 times a week (efforts – 15 s long with the 120 s interval among series). Changes considered: HE from 447±97 to 528±76 N·m (18%) after 4 weeks of training and to 547±22 N·m (22%) after the 1st week from the experiment ($p<0.05$); HF from 181±27 to 198±28 N·m (9%) after 3 weeks of training and to 194±32 N·m (7%) after the 1st week from the research ($p<0.05$); KE from 276±44 to 258±46 N·m (6%), ($p<0.05$) and the insignificant decrease to 273±50 N·m (-1%) after 2 weeks from the experiment; KF form 135±26 to 143±24 N·m (6%) after 4 weeks of training and to 154±29 N·m (14%) after the 1st week from the research ($p<0.05$); PF from 237±44 to 242±37 N·m (2%) and to 258±34 N·m (34%) after 2 weeks from the experiment ($p<0.05$).

Students examined in our work presented lower values of the hip extensors, flexors and knee joint extensors torque in comparison to the group examined by Fidelus *et al.* [17]. The percentage muscles torque changes obtained after the sprint training in our research are lower than in the above author’s work [17]. However, the direction of observed in groups S10 and S5 changes is similar as regards the hip extensors and flexors, knee joint flexors (with the exception of S10) and plantar flexors. In the case of the knee joint extensors this direction is different. We are not able to explain fully what caused differences in the direction of the muscles torque changes observed in the research of Fidelus *et al.* [17] and ours alike occurring in our study changes of the knee joint extensors and hip flexors torque dependently on the performed training. The variety of the muscles torque direction in work of Fidelus *et al.* [17] and our paper might have been caused by differentiated exercises applied to examined subjects. Ericson stated in his research [15] that the pedalling rate does not changes proportions of the performed in respective joints work during the total effort which is put into the one full cycle ergometer circle. The respective joints work ratio in the phase of pushing amounted to (0-180º): HE–28.3%; HF–7.8%; KE–35.3%; KF–11.2%; PF–17.4% and in the phase of rising (180-360º): HE–37.6%; HF–3.8%; KE–24%; KF–4.5%; PF–30.1%. This data show that in the ancle-tibial joint muscles work throughout the pedalling cycle - in the hip joint muscles work alternately: positively in a phase of pushing (0-180º), negatively at the beginning (180-278º) and next positively (270-360º) in the phase of rising; in the knee joint muscles work positively in the pushing phase (0-180º) and in the phase of raising alternately: positively (180-270º) and negatively (270-360º). Hence, we are surprised by such a significant differences between examined groups considering the percentage torque changes of the knee joint extensors and flexors, hip flexors and plantar flexors.

Obtained by examined subjects (groups S5 and W80) values of the plantar flexors MT may suggest that the pedalling rate growth excludes this group of muscles from work (the lack of significant after training MT changes). It is coherent with the results gained by McCartney *et al.* [28] and Sargeant *et al.* [33] who stated that the power produced on pedals decreases along with the growth of the pedalling rate (during the effort with the stable force). Also the result of Patterson and Moreno [31] suggests that the 90-110 rpm pedalling may minimize the force with which pedals are pushed. Ericson *et al.* 1986 and Ericson [15] believe that the sprint abilities belong to the contractible and resilient muscle characteristics. The cycling involves mostly the concentric work with the small dose of the eccentric work, especially of the knee joint extensors. In the opinion of Linossier *et al.* [27] the cycle ergometer is the most proper equipment for the development of some specific contractible adaptation of the quadriceps of thigh (producing 40% of power during pedalling) to the sprint training. Hereof, the result of adopted two sprint trainings differentiated only by the load appended on the cycle ergometer scale is quite astonishing.

Group S5 performing maximal efforts with higher pedalling rate and lower intensity than group S10 obtained bigger changes of the hip and knee joint extensors torque. On the other hand, Urbanik [40] conducting research in which subjects performed maximal jumps on the plane training equipment with and without some additional load (it caused smaller speed while jumping) observed that the percentage growths of the hip and knee extensors and plantar flexors torque were reached by group jumping without the additional load. From results attained by Opaszowski and Buśko [30] and Buśko *et al.* [10] springs that the singular endurance and sprint training (such as in our research for groups S10 and W45) causes decrease of the cortisol concentration with the simultaneous growth of the testosterone concentration (it points at the anabolic changes increase) and singular intermittent training on the cycle ergometer (such as in our research for groups S5 and W80) effects in the cortisol concentration growth what may point at the catabolic transformations dominance. It probably could have been the reason of observed, under the influence of applied in those researches cycle ergometer trainings, differences considering muscle torque values.

Basing on the static muscles torque measurements authors of some of works presented in references calculated so called “flexors-to-extensors index” [13,42]. In the paper of Trzaskoma [38] this index amounted in juniors playing tennis to 0.48 (knee joint) and 0.15 (hip joint). Bober and Hay [5] accomplished in non-athletes the following flexors-to-extensors ratios: knee joint – 0.46; hip joint – 0.47. The flexors-to-extensors ratio calculated by Jaszczuk *et al.* [23] for 9 sport disciplines representatives amounted to: knee joint from 0.39 to 0.57 (it was changing in a narrow section of 0.49-0.54 for 6 disciplines agents) and hip joint from 0.18 to 0.25. In the work of Buśko [7] the flexors-to-extensors ratio amounted to 0.62 in the knee joint of juniors up to 19 years old and to 0.68 in senior basketball players. In the case of the hip joint it amounted respectively to 0.41; 0.37 and 0.36. In the paper of Buśko et al. [11] the knee joint flexors-to-extensors ratio amounted to 0.47 in the strength track athletics contestants and in non-athletes to 0.63. In the research of Trzaskoma and Trzaskoma [39] the hip and knee joint flexors-to-extensors indices amounted to 0.20 and 0.43 respectively and were obtained by 70 athletes of various sport disciplines. Results regarding the knee joint flexors-to-extensors index attained in our work are coherent with results of Buśko [7] and Buśko et al. [11] who examined non-athletes and basketball players. The index reached for the hip joint seems to be congenial to values presented in the study of Bober and Hay [5]. Nevertheless, our researches results show that the fact of the significant changeability of the flexors-to-extensors index after 4 week training and its normalisation after 2 weeks from trainings must be taken into account while the indices comparison.

The dependence between the muscles strength and body mass or body composition was described in a number of works [35]. In the paper of Bober and Hay [5] the sum of 8 muscle groups torque correlated significantly with the body mass (r=0.51). Authors found surprising the lack of correlation between the body mass and an arm extensors and hip flexors torque. In the research of Le Chevalier *et al.* [25] any connection between the mass of quadriceps of thigh and its torque in the static conditions (r=0.33) was found. Next, Dworak *et al.* [14] stated the significant dependence between the body mass and muscles torque: HE (r=0.46); HF (r=0.69); KE (r=0.30); KF (r=0.37); PF (r=0.45). Buśko [6] noticed the significant relation of the female basketball players body mass and torque of: hip extensors and flexors in cadets and juniors, knee joint in cadets and seniors, trunk in cadets and seniors and the sum of 11 muscle groups in cadets, juniors and seniors. Buśko [7] observed also the significant relationship between the body mass and torque of hip extensors and 11 muscle groups sum in basketball cadets, juniors and seniors. Hip flexors and extensors, the knee joint flexors and the trunk extensors correlated significantly in cadets and juniors only and the plantar flexors in juniors and seniors. In works of Buśko and Kłossowski [8] and Buśko [9] any connection between the body mass and torque of the knee joint, hip or trunk flexors and extensors, plantar flexors or the sum of 11 muscle groups was found in basketball strikers, wing and midfield male and female players. In the paper of

Janiak *et al.* [22] the absolute body mass value converted to the logarithmic value correlated significantly with the knee joint flexors (r=0.395) and extensors

Table 4
Coefficients of the correlation between the body mass and hip and knee joint extensors and flexors torque (HE, HF, KE, KF respectively), plantar flexors torque (PF), sum of 5 examined muscle groups (SUM) and flexors-to-extensors index (FEI) in the knee (K) and hip (H) joint for measurements taken before the experiment (0), after 4 week training (4) and after 2 weeks after training (6)

Variable	No	S10 (n=9)	S5 (n=11)	W80 (n=12)	W45 (n=11)
HE [N·m]	0	0.53	0.71*	0.67*	0.58*
	4	0.50	0.56	0.43	0.42
	6	0.49	0.74*	0.70*	0.55
HF [N·m]	0	0.58	0.71*	0.71*	0.55
	4	0.70*	0.78*	0.68*	0.72*
	6	0.77*	0.76*	0.64*	0.36
KE [N·m]	0	0.59	0.86*	0.65*	0.42
	4	0.50	0.85*	0.77*	0.12
	6	0.47	0.80*	0.60	0.48
KF [N·m]	0	0.65	0.81*	0.77*	0.63*
	4	0.51	0.87*	0.73*	0.64*
	6	0.50	0.66*	0.69*	0.61*
PF [N·m]	0	0.64	0.76*	0.65*	0.64*
	4	0.40	0.63*	0.49	0.58*
	6	0.53	0.76*	0.59	0.60*
SUM [N·m]	0	0.65	0.86*	0.78*	0.68*
	4	0.55	0.86*	0.76	0.64*
	6	0.59	0.86*	0.74*	0.75*
FEI_H	0	0.16	0.08	-0.43	-0.16
	4	-0.24	0.11	-0.03	0.39
	6	0.07	-0.12	-0.07	0.04
FEI_K	0	0.25	-0.23	0.34	0.61*
	4	-0.02	0.31	0.35	0.63*
	6	0.06	-0.03	0.63*	0.28

S10 - the sprint training (load - 10% BW); S5 - the sprint training (load -5% BW); W80 - the endurance training (80 rpm); W45 - the endurance training (45 rpm); *- $p<0.05$

(=0.621); hip joint flexors (r=0.693) and extensors (r=0.687) and the trunk flexors (r=0.766) and extensors (r=0.674) in an elite fencers, boxers and judo players. In our research the significant connection of the body mass and examined groups of muscles torque and the sum MT of 5 examined muscle groups in all subjects was observed. Moreover, it did not change significantly under the influence of applied training (Table 4).

To sum up, results obtained in this work do not confirm above authors conclusions as regards the cycle ergometer training influence on the muscle torque development. However, the research results enable to form some thesis claiming that the cycle ergometer training elicits the hip extensors torque growth. Torque of other joints muscles depend on performed trainings:

- sprint training caused the growth of the hip flexors torque and the endurance test – the MT decrease in this joint.
- Sprint training executed with the load equal 5% BW and endurance test with the pedalling rate equal 45 rpm effected in the growth of the knee joint extensors torque.
- Sprint training performed with the load equal 10% BW and endurance test with the pedalling rate equal 45 rpm caused the growth of the plantar flexors torque.
- All kinds of training did not effect in significant change of the knee joint flexors torque.

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Accepted for publication 29.07.2002

Acknowledgements

This work was conducted in a frame of the Academy of Physical Education own research programme and was supported by KBN in the year 2000.

It was accepted by the Department’s head-master.