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Measurement of maximal isometric torque and muscle fatigue index of the knee muscles in male athletes

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Purpose: The aim of the paper was to analyse variables related to the force and fatigue of knee muscles in the right and left lower limbs among 17 male athletes. *Methods*: For both muscle groups, maximal isometric torque (F_{max}) was determined with the use of Biodex System 4 Pro and the values of muscle fatigue index ($FATI_{1-3}$) were calculated. *Results*: A significant difference was observed between the groups of short- and long-distance runners in the values of all fatigue indices of knee joint extensor muscles in the right limb. In turn, between the groups of athletes who had trained for 2–4 years or for 4.5–7 years and the group who had trained for 7.5–13 years, significant differences were observed in the values of all fatigue indices of knee joint flexor muscles in the right limb. The group training for 3–12 hours per week and the group training for 12.5–18.0 hours per week in the sports club differed significantly in the value of the maximal isometric torque of knee joint flexor muscles in the right limb and in the values of some fatigue indices (FAT_1, FAT_3) for knee joint flexor muscles in the right limb. The study reported numerous positive correlations between the assumed characteristics and the investigated variables of knee joint extensor and flexor muscles in the right and left lower limbs. *Conclusions*: Athletes present certain changes in variable values and positive correlations between some characteristics and investigated variables of selected knee muscles.

Key words: *male athletes, maximal isometric torque, fatigue index, knee joint muscles*

1. Introduction

Athletics is a sports discipline including many events, e.g., runs, jumps, throws, and combined track and field events. Training, often based on individual plans, emphasizes the competitors' fitness, speed, and endurance. Obtaining high movement speeds by an athlete demands an ability to develop especially high muscle force values [7], [12].

Determining the isometric torques of various muscle groups is allowed by numerous measurement systems, including the diagnostic and training Biodex System 4 Pro [6], [13], [14], [17], [18].

Endurance is the ability of an organism to perform physical effort with specific intensity and efficiency, at the same time maintaining increased resistance to fatigue. Muscle fatigue denotes a state of changing ability of a muscle to maintain a specific force level or a static body position. This is expressed as a decrease in the ability to expend force as a result of a rising feeling of effort and is subjected to various mechanisms (dependent also on age and sex) and adaptation processes [3]–[5], [16], [18]–[20].

Muscle fatigue has its objective measures, which are determined with various methods [2], [8], [11]. These include fatigue level estimation (FATI) [6], [14], [15]. The available literature, however, lacks studies indicating the value of the muscle fatigue index ($FATI_1$, $FATI_2$, and $FATI_3$) in athletes.

The aim of the paper was to analyse the levels of maximal isometric torque (F_{max}) and fatigue ($FATI_{1-3}$) of knee joint extensor and flexor muscles in the right and left lower limbs in the conditions of an isometric test among males training athletic sports, as well as to indicate the existing correlations.

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2. Materials and methods

Ethical approval for this study was provided by the Bioethics Committee of Collegium Medicum of the Nicolaus Copernicus University in Toruń, Poland (No. KB 330/2014). The participants or their legal guardians (in the case of participants aged under 18 years) were informed of the procedure used in the study and provided their written consent. The study was performed according to the Declaration of Helsinki. The study was conducted in the Laboratory of Physical Effort of the Institute of Physical Education at Kazimierz Wielki University in Bydgoszcz, Poland, in January 2016. The study involved subjects regularly participating in athletic training in sports clubs of the city of Bydgoszcz. Inclusion criteria required the participants to have been free of all limb and spinal injuries for 3 months prior to the study. Overall, 20 participants were excluded.

The study involved 17 male athletes aged 18–25 years, with average: body mass – 76.6 ± 5.9 kg, free fat mass – 68.6 ± 4.4 kg, fat tissue – 8.5 ± 3.6 kg and body height – 184.5 ± 5.9 cm, training various athletic disciplines. The participants were grouped in accordance with selected characteristics (Table 1).

The said groups of athletes underwent numerous investigations based on the methodological assumptions provided previously [14], [15].

All study subjects underwent isometric examinations of knee joint extensor and flexor muscles in the right and left lower limbs, at the angle of 60°. Prior to the test, each participant undertook a 15-minute individual warm-up. Then, the range of motion (ROM) in the knee joint was determined. The value of 0° was assumed for the maximal knee joint extension, up to 90° with flexion. The next step was to extend the limb and relax the quadriceps femoris muscle in order to adjust for the influence of gravity on the value of the isometric torque generated during the eccentric and concentric phases of an isometric contraction. Subsequently, a dynamometer immobilized the limb at the angle of 60°. The examination consisted in counteracting the dynamometer resistance with the greatest possible force in the given angle. The test of the right lower limb was first performed for extensors, and then for flexors. Later on, the examination was repeated for the left lower limb. The total test duration equalled 105 seconds. For the first 30 seconds, the subject was expected to generate force with the use of knee joint extensor muscles; then, a 45-second rest followed, after which knee joint flexor muscles generated force for the next 30 seconds. During the test, the participants received verbal support from the person who conducted the examination, they were also visually motivated, as the diagram of the generated isometric torque was presented on the monitor screen in real time.

In order to analyse the influence of the isometric contraction on the maximal isometric torque and fatigue indices of knee joint extensor and flexor muscles among the studied athletes, we performed examinations with the use of the Biodex System 4 Pro device (Biodex Medical Systems Inc., Shirley, NY, USA). During the test, the Biodex system registered the isometric torque value every 10 ms.

The reported maximal isometric torque (F_{max}) values also served to calculate muscle fatigue indices ($FATI_{1–3}$), in accordance with the following formulas.

$$FATI_1 = 100\% * \left(1 - \left(\frac{AUFC_{0–30}}{F_{\max 0–5} * 30}\right)\right) \quad (1)$$

where: $AUFC_{0–30}$ (area under the force vs. time curve) – area under the obtained isometric torque vs. time curve, counted for seconds 0–30 of the test; $F_{max0–5}$ – maximal isometric torque obtained within the first 5 seconds of the test;

$$FATI_2 = 100\% * \left(1 - \left(\frac{AUFC_{5–30}}{F_{\max 0–5} * 25}\right)\right) \quad (2)$$

Table 1. Characteristics of athlete groups partaking in the isometric examination

Characteristic	Group			Total
Long-distance runner (L-DR), short-distance runner (S-DR), not running (NR)	I	II	III	L-DR, S-DR, NR, n = 17
	L-DR, n = 6	S-DR, n = 6	NR, n = 5	
Years of training	I	II	III	2–13, n = 17
	2–4, n = 8	4.5–7, n = 4	7.5–13, n = 5	
Number of training hours in the sports club per week	I	II		3–18, n = 17
	3–12, n = 7	12.5–18, n = 10		
Additional training (outside the sports club), hours per week	I	II		0–3, n = 17
	Yes, 2–3, n = 7	0, n = 10		

where: $AUFC_{5–30}$ – area under the obtained isometric torque vs. time curve, counted for seconds 5–30 of the test; $F_{\max 0–5}$ – maximal isometric torque obtained within the first 5 seconds of the test;

$$FATI_3 = 100\% * \left(1 - \left(\frac{AUFC_{TPM-30}}{F_{\max 0–5} * (TPM - 30)}\right)\right) \quad (3)$$

where: *TPM* (time point of maximum) – time in which maximal isometric torque was obtained within the first 5 seconds of the test; $AUFC_{\text{TPM–30}}$ – area under the obtained isometric torque vs. time curve, counted from *TPM* to second 30 of the test; $F_{\max 0–5}$ – maximal isometric torque obtained within the first 5 seconds of the test.

The AUFC value was calculated with the use of numerical integration, with the trapezoidal rule application.

2.1. Statistical analysis

All the values of the maximal isometric torque ($F_{\max}$) and muscle fatigue indices ($FATI_{1–3}$) of the extensor and flexor muscles in the athletes' both knee joints (depending on various elements characteristic of the subjects) underwent statistical analysis with the STATISTICA PL software. Mean differences were determined with the ANOVA analysis of variance and Tukey's honest significant difference (HSD) test, with the significance level of $p < 0.05$. Also, the value of the correlation coefficient (R) was established between the studied characteristics and the values of the investigated variables.

3. Results

In Table 2 the values of the studied variables for all participants are presented. The analysis of the results for the $F_{\max}$ values in the whole examined group of athletes showed that the knee joint extensor muscles in the right and left lower limbs were able to generate higher $F_{\max}$ than the knee joint flexor muscles. These associations were not observed with the determined values of $FATI_{1–3}$ indices.

Table 3 includes the values of the studied variables depending on the running distance covered by the athletes. One can conclude that between the groups of short- and long-distance runners, a statistically significant difference was observed in the value of fatigue indices for the knee joint extensor muscles in the right, dominant limb (in group I: $FATI_1$ = 23.09%, $FATI_2$ = 23.38%, $FATI_3$ = 22.12%; in group II: $FATI_1$ = 9.73%, $FATI_2$ = 7.57%, $FATI_3$ = 7.53%).

Table 4 shows the values of the studied parameters depending on the competitors' training level (years of training). Between the groups of athletes who had trained for 2–4 years or for 4.5–7 years and the group who had trained for 7.5–13 years, statistically significant differences were observed in the values of all fatigue indices of knee joint flexor muscles in the right lower limb (in group I: $FATI_1$ = 25.7%, $FATI_2$ = 25.62%, $FATI_3$ = 24.51%; in group II: $FATI_1$ = 29.91%, $FATI_2$ = 29.33%, $FATI_3$ = 28.44%; in group III: $FATI_1$ = 13.21%, $FATI_2$ = 10.01%, $FATI_3$ = 10.64%).

Table 5 provides the study results with reference to the number of hours per week devoted by the competitor to training in the sports club. It can be concluded that between the group training for 3–12 hours and the group training for 12.5–18.0 hours, statistically significant differences were observed in the values of maximal isometric torque of knee joint flexor muscles in the right limb (in group I: $F_{\max}$ = 146.36 Nm; in group II: $F_{\max}$ = 124.32 Nm). Also, statistically significant differences were reported for selected fatigue indices of knee joint flexor muscles in the right leg (in group I: $FATI_1$ = 28.90%, $FATI_3$ = 27.50%; in group II: $FATI_1$ = 18.90%, $FATI_3$ = 17.05%).

The influence of additional training undertaken outside the sports club on all the studied variables was also assessed. No statistically significant differences ($p > 0.05$) were found between the evaluated groups of athletes.

Table 2. Maximal isometric torque and fatigue indices values for selected muscles in the whole group of athletes

Knee joint muscles/Leg	Variables		
Maximal isometric torque, $F_{\max}$ [Nm], n = 17, $\overline{X}$ ± SD			
E/RL	291.18 ± 49.25[a]		
F/RL	133.39 ± 21.57[b]		
E/LL	279.43 ± 44.32[a]		
F/LL	124.88 ± 22.26[b]		
Fatigue index, FATI [%], n = 17, $\overline{X}$ ± SD			
	$FATI_{1\ (0–30\ s)}$	$FATI_{2\ (5–30\ s)}$	$FATI_{3\ (TPM–30\ s)}$
E/RL	15.19 ± 10.14	14.01 ± 11.81	13.49 ± 10.94
E/LL	13.55 ± 8.39	12.15 ± 10.32	11.51 ± 9.75
F/RL	23.02 ± 9.59	21.90 ± 11.28	21.36 ± 10.29
F/LL	18.66 ± 10.07	17.57 ± 11.30	17.10 ± 10.29

E/RL – extensors/right leg, E/LL – extensors/left leg, F/RL – flexors/right leg, F/LL – flexors/left leg, TPM – time point of maximum, a:b – significant differences between extensors and flexors at $p < 0.05$.

Table 3. Maximal isometric torque and muscle fatigue index ($FATI_{1–3}$) values depending on the running distance covered by the athletes

Knee joint muscles/Leg	Group I $n = 6$ $\overline{X} \pm SD$	Group II $n = 6$ $\overline{X} \pm SD$	Group III $n = 5$ $\overline{X} \pm SD$
Maximal isometric torque, F_{max} [Nm], $\overline{X} \pm SD$			
E/RL	284.75 ± 50.18	285.25 ± 52.20	306.00 ± 52.52
F/RL	145.07 ± 18.42	122.57 ± 18.98	133.39 ± 21.57
E/LL	287.40 ± 41.24	263.80 ± 5618	279.43 ± 34.91
F/LL	129.65 ± 29.87	123.83 ± 10.64	120.40 ± 25.78
Fatigue index, FATI [%], $\overline{X} \pm SD$			
$FATI_{1\ (0–30\ s)}$			
E/RL	23.09 ± 8.88[a]	9.64 ± 7.97[b]	12.36 ± 9.11[a, b]
E/LL	17.16 ± 7.70	10.27 ± 9.33	13.16 ± 7.90
F/RL	28.14 ± 9.04	16.57 ± 9.49	24.60 ± 6.96
F/LL	18.64 ± 9.94	15.98 ± 9.52	21.90 ± 12.04
$FATI_{2\ (5–30\ s)}$			
E/RL	23.38 ± 9.44[a]	7.57 ± 9.53[b]	10.48 ± 11.12[a, b]
E/LL	16.72 ± 9.12	7.93 ± 11.61	11.72 ± 9.77
F/RL	27.62 ± 11.04	14.65 ± 11.08	23.75 ± 8.41
F/LL	17.41 ± 11.17	14.63 ± 10.56	21.27 ± 13.62
$FATI_{3\ (TPM–30\ s)}$			
E/RL	22.12 ± 8.44[a]	7.53 ± 8.94[b]	10.27 ± 10.59[a, b]
E/LL	15.82 ± 8.26	7.36 ± 11.27	11.30 ± 9.11
F/RL	26.82 ± 9.5	14.50 ± 9.90	23.03 ± 8.36
F/LL	17.32 ± 9.87	14.5 ± 10.13	19.97 ± 12.37

E/RL – extensors/right leg, E/LL – extensors/left leg, F/RL – flexors/right leg, F/LL – flexors/left leg, TPM – time point of maximum, a, b – significant differences between groups at $p < 0.05$.

Table 4. Maximal isometric torque and muscle fatigue indices values depending on the athletes' years of training

Knee joint muscles/Leg	Group I $n = 8$ $\overline{X} \pm SD$	Group II $n = 4$ $\overline{X} \pm SD$	Group III $n = 5$ $\overline{X} \pm SD$
1	**2**	**3**	**4**
Maximal isometric torque, F_{max} [Nm], $\overline{X} \pm SD$			
E/RL	313.13 ± 51.19	268.73 ± 34.73	274.02 ± 48.75
F/RL	137.85 ± 23.39	125.95 ± 27.99	132.22 ± 14.78
E/LL	301.04 ± 40.83	255.25 ± 37.50	264.20 ± 45.55
F/LL	130.89 ± 28.11	110.0 ± 16.10	126.52 ± 11.47
Fatigue index, FATI [%], $\overline{X} \pm SD$			
$FATI_{1\ (0–30\ s)}$			
E/RL	13.95 ± 10.87	16.72 ± 8.25	15.95 ± 12.11
E/LL	13.91 ± 7.45	12.60 ± 10.50	13.74 ± 10.02
F/RL	25.70 ± 8.53[a]	29.91 ± 3.99[a]	13.21 ± 6.82[b]
F/LL	20.25 ± 12.05	22.16 ± 7.08	13.31 ± 7.81
$FATI_{2\ (5–30\ s)}$			
E/RL	12.62 ± 12.76	16.27 ± 8.87	14.41 ± 14.30
E/LL	12.86 ± 8.93	10.61 ± 13.09	12.25 ± 12.43
F/RL	25.62 ± 10.10[a]	29.33 ± 5.09[a]	10.01 ± 7.18[b]
F/LL	19.84 ± 13.42	21.50 ± 7.51	10.78 ± 8.39
$FATI_{3\ (TPM–30\ s)}$			
E/RL, $FATI_3$	12.20 ± 11.82	15.57 ± 8.24	13.88 ± 13.26
E/LL, $FATI_3$	12.34 ± 8.25	9.7 ± 12.62	11.63 ± 11.73
F/RL, $FATI_3$	24.51 ± 9.22[a]	28.44 ± 4.96[a]	10.64 ± 6.55[b]
F/LL, $FATI_3$	18.56 ± 12.15	21.39 ± 6.23	11.34 ± 8.47

E/RL – extensors/right leg, E/LL – extensors/left leg, F/RL – flexors/right leg, F/LL – flexors/left leg, TPM – time point of maximum, a:b – significant differences between groups at $p < 0.05$.

Table 5. Maximal isometric torque and muscle fatigue indices values depending on the number of the athlete's training hours per week

Knee joint muscles/Leg	Group I $n = 7$ $\overline{X} \pm SD$	Group II $n = 10$ $\overline{X} \pm SD$
Maximal isometric torque, F_{max} [Nm], $\overline{X} \pm SD$		
E/RL	309.97 ± 51.13	278.02 ± 45.85
F/RL	146.36 ± 24.58[a]	124.32 ± 14.20[b]
E/LL	304.14 ± 44.30	262.13 ± 37.09
F/LL	131.51 ± 29.64	120.23 ± 15.40
Fatigue index, FATI [%], $\overline{X} \pm SD$		
$FATI_{1\ (0–30\ s)}$		
E/RL	14.09 ± 10.70	15.96 ± 10.23
E/LL	15.07 ± 5.87	12.49 ± 9.95
F/RL	28.90 ± 8.18[a]	18.90 ± 8.55[b]
F/LL	19.68 ± 10.62	17.94 ± 10.18
$FATI_{2\ (5–30\ s)}$		
E/RL	12.87 ± 12.04	14.80 ± 12.23
E/LL	14.00 ± 6.85	10.86 ± 12.39
F/RL	28.49 ± 9.56	17.30 ± 10.39
F/LL	19.31 ± 12.14	16.35 ± 11.18
$FATI_{3\ (TPM–30\ s)}$		
E/RL	12.47 ± 11.14	14.20 ± 11.35
E/LL	13.49 ± 6.25	10.12 ± 11.74
F/RL	27.50 ± 9.00[a]	17.05 ± 9.19[b]
F/LL	18.67 ± 10.5	16.01 ± 10.56

E/RL – extensors/right leg, E/LL – extensors/left leg, F/RL – flexors/right leg, F/LL – flexors/left leg, TPM – time point of maximum, a, b – significant differences between groups at $p < 0.05$.

In Tables 6 and 7 the values of the correlation coefficient (R) between the studied characteristics (signifi-

cant with $p < 0.05$) are presented. Positive correlations between some parameters can be observed.

Table 6. Values of the correlation coefficient (R) between selected characteristics and F_{max} and FATI of knee joint extensor and flexor muscles in the right and left lower limbs among the athletes ($p < 0.05$)

Characteristic/ Variables	F_{max}			$FATI_{1\ (0–30\ s)}$	
	E/LL	F/RL	F/LL	E/LL	F/RL
Years of training	–	–	–	–	0.6047
Number training hours in the club per week	–	0.5088	–	–	0.5226
F_{max} E/RL	0.8806	0.5395	0.5940	–	–
F_{max} F/RL	0.7202	–	0.6504	–	–
F_{max} E/LL	–	–	0.6638	–	–
$FATI_{1\ (0–30\ s)}$ E/LL	–	–	–	0.5572	–

E/LL – extensors/left leg, F/RL – flexors/right leg, F/LL – flexors/left leg, F_{max} – maximal isometric torque, $FATI_{1\ (0–30\ s)}$ – fatigue index (0–30 s).

4. Discussion

The analysis of the study results concerning the values of the maximal isometric torque (F_{max}) of the muscles in the whole group of athletes proved that the knee joint extensor muscles in the right and left limbs were able to generate higher F_{max} than the knee joint flexor muscles. These differences were not observed for the values of all $FATI_{1–3}$ indices.

A study performed among 30 volunteers (13 men and 17 women) [15] reported the value of F_{max} equal to 167 Nm for the right and 159 Nm for the left extensors, as well as 88 Nm for the right and 85 Nm for the left flexors of the knee joint. In turn, the values of FATI were within the following ranges: from $FATI_1$ = 20%, through $FATI_2$ = 10%, to $FATI_3$ = 20% for the right lower limb extensor muscles; from $FATI_1$ = 22%, through $FATI_2$ = 9%, to $FATI_3$ = 21% for the left lower limb extensors; from $FATI_1$ = 22%, through $FATI_2$ = 10%, to $FATI_3$ = 21% for the right lower limb flexor muscles; and from $FATI_1$ = 22%, through $FATI_2$ = 10%, to $FATI_3$ = 22% for the left lower limb flexors.

Table 7. Values of the correlation coefficient (R) between selected characteristics and FATI of knee joint extensor and flexor muscles in the right and left lower limbs among the athletes ($p < 0.05$)

Characteristic/Variables	$FATI_{2\ (5–30\ s)}$				$FATI_{3\ (TPM–30\ s)}$			
	E/RL	E/LL	F/RL	F/LL	E/RL	E/LL	F/RL	F/LL
Years of training	–	–	0.6234	–	–	–	0.6188	–
Number training hours in the club per week	–	–	0.5153	–	–	–	0.5352	–
$FATI_{1\ (0–30\ s)}$ E/RL	0.9967	0.5600	–	–	0.9948	0.5546	–	–
$FATI_{1\ (0–30\ s)}$ E/LL	0.5695	0.9969	–	–	0.5894	0.9936	–	–
$FATI_{1\ (0–30\ s)}$ F/RL	–	–	0.9888	–	–	–	0.9923	–
$FATI_{1\ (0–30\ s)}$ F/LL	–	–	–	0.9968	–	–	–	0.9956
$FATI_{2\ (5–30\ s)}$ E/RL	–	0.5746	–	–	0.9992	0.5696	–	–
$FATI_{2\ (5–30\ s)}$ E/LL	0.5953	–	–	–	–	0.9984	–	–
$FATI_{2\ (5–30\ s)}$ F/RL	–	–	–	–	–	–	0.9932	–
$FATI_{2\ (5–30\ s)}$ F/LL	–	–	–	–	–	–	–	0.9963
$FATI_{3\ (TPM–30\ s)}$ E/RL	–	–	–	–	–	0.5904	–	–

E/RL – extensors/right leg, E/LL – extensors/left leg, F/RL – flexors/right leg, F/LL – flexors/left leg, $FATI_{1\ (0–30\ s)}$ – fatigue index (0–30 s), $FATI_{2\ (5–30\ s)}$ – fatigue index (5–30 s), $FATI_{3\ (TPM–30\ s)}$ – fatigue index (TPM–30 s), TPM – time point of maximum.

The above-mentioned F_{max} values are lower than those obtained in the own study. A reason for these differences was undoubtedly the fact than the participants of the quoted study were workers of a research and rehabilitation centre, and not professional athletes. Moreover, the underestimation of the values could have resulted from the participation of women, who, in general, do not reach as high F_{max} values as men, which was proved in research that reported a significant impact of sex on skeletal muscles responses during isometric contraction [5]. Another study [8] also showed significant side-to-side differences in the antagonist muscles activity and maximal muscle isometric torque, especially with reference to the vastus medialis in females, during maximal isometric endurance test of the knee. In turn, during a high-intensity 30-second unilateral maximal effort isometric leg extension exercise, the activation of the contralateral non-exercising limb knee extensor is independent of the sex of individuals [3]. During isotonic effort, with or without restricted blood flow, a slightly higher influence of endurance of knee joint extensor and flexor muscles in the lower limbs on fatigue was reported in women than in men [9]. Another finding is that the sex-related difference in the skeletal muscle (quadriceps) fatigue resistance is not explicable by gender differences in motivation, muscle size, oxidative capacity, or blood flow, but might be related to differences in fibre type composition [20].

The detailed investigation proves that the group of short-distance runners presented higher FATI values of extensor muscles in the right lower limb as compared with the group of long-distance runners. This is partially supported by another study, which aimed at determining the FATI values of the quadriceps among athletes practising endurance and strength disciplines [11]. It was observed that the mean quadriceps FATI value increased by 40% in the endurance sports group and by 184% in the strength sports group. Additionally, the drop in the F_{max} value after each exercise repetition was considerably smaller in the endurance than in the strength sports group. The individual advantage in the fatigue resistance of the vastus lateralis muscle when performing a repeated sprint task was associated with a lower anaerobic power reserve [10].

In the own study, statistically significant differences were also reported for some FATI values between groups appointed in accordance with the number of training years. However, no changes were observed for F_{max}. A higher training level (longer training practice) undoubtedly resulted in an increase of adaptation to fatigue of knee joint flexor muscles in the right, dominant lower limb. Training status seems to influence the acute reaction to intense strength training, and fatigue has a major impact on muscle performance [1].

The values of the correlation coefficient (R) determined in the own study point at a statistically significant ($p < 0.05$) correlation between the level of the athlete's training (years of training) and $FATI_1$, $FATI_2$, and $FATI_3$ of flexor muscles in the right lower limb. The time devoted to training in the club (hours per week) was also correlated with the values of F_{max}, $FATI_1$, $FATI_2$, and $FATI_3$ of knee joint flexor muscles in the right lower limb. Positive correlations were observed between F_{max} values of knee joint extensor and flexor muscles in the left and right legs. The study also reported positive correlations between FATI values for the right leg extensors and the knee joint extensors in the left limb. However, no such correlation was noted for knee joint flexor muscles.

As a comparison, previous research [15] showed negative correlations between the F_{max} and $FATI_1$ ($R = –0.45$) and F_{max} and $FATI_3$ ($R = –0.46$) of flexor muscles among the studied men and women; no correlation was observed between F_{max} and FATI. It should be assumed that the differences between the presented own findings and those obtained in the quoted study result from the specificity and the level of training (lack of sports training, as a matter of fact, in the study group, consisting of men and women).

5. Conclusions

The research performed in the conditions of an isometric test proved that in men aged 18–25 years representing different athletic disciplines, specific values of the F_{max} and $FATI_{1–3}$ variables were stated for knee joint extensor and flexor muscles. Short-distance athletes were characterized by a higher susceptibility to fatigue of the studied knee muscles than the long-distance participants, and a longer training practice led to an increase in the resistance to fatigue of knee joint flexor muscles in the right (dominant) leg. In turn, a greater number of hours per week devoted to training in the sports club resulted in lowering the ability to generate maximal isometric torque, causing an increased resistance to fatigue of knee joint flexor muscles in the right lower limb. In the studied athletes, there are numerous positive correlations (R) between selected characteristics (training practice, time devoted to training in the sports club per week) and some values of the investigated variables (F_{max} and $FATI_{1–3}$) and between the values of these variables for selected muscles of the knee joint.

The above-mentioned studies provide valuable information on the resistance to fatigue in the investigated muscle groups and on the change of the "efficiency" level of knee joint muscles during a 30-second maximal voluntary contraction in athletes, which may also be applied in similar analyses referring to physically active and inactive subjects, as well as to post-rehabilitation patients.

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