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Leg strength and power in Polish striker soccer players

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Purpose: The main goal of the present study was to examine muscle strength and power of dominant and non-dominant leg, knee extensors and flexors, and their correlations with jumping performances in soccer players. A secondary aim was to evaluate muscle sense. *Methods*: 31 male professional strikers (age 20.9 ± 2.3 years, body mass 75.1 ± 6.6 kg, body height 179.5 ± 4.7 cm) participated in the study. The power output of lower extremities and the height of rise of the body mass centre during vertical jumps were measured using a force plate. The maximum muscle torque of the flexors and extensors of the knee were measured under isometric conditions using a special isometric torquemeter. Force sense was measured in isometric conditions in two tests: (a) fifty percent of the maximal voluntary contraction was set as a value of target force and the participants were instructed to reproduce the target force, (b) the participants attempted to develop a torque reproducing a sine course within the range of 10 to 50% of MVC performed. *Results*: A direct relationship was observed between the peak muscle torque in knee extensors developed during isokinetic contraction at all velocities and power and height of three types of vertical jumps ($p < 0.05$). No correlation was observed between jumping performance and muscle torque under isometric condition. No differences were found in strength and jumping abilities as well as in force sense between dominant and non-dominant legs. *Conclusions*: This study offered a comprehensive and complete evaluation of leg muscle strength, sense and power, with the use of using force plate and isokinetic dynamometry.

Key words: *force sense, height of jump, isokinetic, peak torque, power, striker soccer players*

1. Introduction

Soccer players should be able to maintain high level of motor skills over the whole soccer season, which usually lasts from 10 to 11 months [21]. Fatigue caused by training and competition may deteriorate athlete's effectiveness during the game [1] or elevate the injury risk [22]. The knee is the joint which is the most prone to injuries [14]. The knee extensors play a dominant role during jumps and kicking the ball [12]. Furthermore, the knee flexors are mainly responsible for stabilization of the joint during numerous accelerations, cuts and slide tackles [7]. These actions can place a substantial load on the neuromuscular system and lead to injuries [5]. Therefore, prevention of injuries is a main concern of coaches and fitness trainers [17]. The basic parameter to predict injury risk and evaluate fitness is hamstrings-to-quadriceps (H/Q) ratio of torques [11]. It is suggested that if the H/Q ratio during an isokinetic contraction at the speed of 60 $deg \cdot s^{-1}$ decreases below 0.6, the risk of injury rises substantially [11]. Another factor enabling prediction of injury risk is the lack of balance of strength between dominant and non-dominant limb [17]. This asymmetry can result from the different movement techniques for both limbs and different playing positions on the field, which requires different skills from players. For example, strikers jump higher, compared to midfielders or defenders [18]. Moreover, strikers

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also develop greater power in legs, compared to midfielders [2].

Other significant skill of soccer players are proprioception abilities. The tasks of the proprioceptive system include control over human motion, based on information from different receptors [15]. In the literature there are various definitions of proprioception (kinaesthetics) [23]. Proprioception is defined as sensing the position and movement of body parts, depending on the proprioceptors located in muscles, tendons and joints that allow the detection of the position and movement without visual control, whereas others, apart from the ability to identify limb position in the space, also emphasize muscle force sense [10].

Although the abovementioned studies have enhanced our understanding of the impact of H/Q ratio on leg injuries, there is little information about the comparison between both legs and the correlation of isokinetic strength with jumping performances [24]. Such information would be of great practical value for practitioners working with soccer players.

Therefore, the aim of the study was to present biomechanical characteristics of motor abilities of soccer players on the striker positions with the emphasis on differences between dominant and non-dominant legs and between knee extensors and flexors.

2. Material and methods

2.1. Participants and study design

31 male professional soccer players (age 20.9 ± 2.3 years, body mass 75.1 ± 6.6 kg, and body height 179.5 ± 4.7 cm) who played as strikers participated in the study. The right leg was dominant for all participants and none of them reported any injury of the lower limb joints for six months prior to the study. Ethical approval for this study was provided by the local ethical committee at the Institute of Sport – National Research Institute in Warsaw, Poland. Participants were informed about all testing procedures. Written informed consent was obtained from participants. The study was performed according to the Declaration of Helsinki.

2.2. Protocols and equipments

The measurements were made after the 5-minute warm-up, consisting of light exercise (i.e., running, circles of the arms, hips and trunk, squats followed by stretching exercises) in the Laboratory of Biomechanics in the following order: jump testing, MVC measurement, measurement of force sense in isometric conditions and isokinetic muscle strength.

Power output and jump height

The power output of lower extremities and the height of the rise of the body mass centre (COM) during vertical jumps were measured using a force plate ("JBA" Zb. Staniak, Poland). The MVJ v. 3.4 software package ("JBA" Zb. Staniak, Poland) was used for measurements. Absolute peak power (P_{max} [W]), relative peak power ($P_{max} \cdot mass^{-1}$ [$W \cdot kg^{-1}$]) and maximum height of rise of the body's COM (h [m]) were calculated from the recorded ground reaction force of the platform [8]. Each participant performed fifteen vertical jumps on the force plate: three jumps of each kind. The characteristics of each jumping test were the following:

ACMJ – akimbo counter-movement jump – a vertical jump from an upright standing position with hands on the hips and counter-movement of the COM before the take-off;

CMJ – counter-movement jump – a vertical jump from a standing erect position, preceded by an arm-swing and counter-movement of the body COM before the take-off;

CMJR – right leg counter-movement jump – a vertical jump from a standing erect position on right leg with left leg bent in knee joint, preceded by an arm swing and counter-movement of the body COM before the take-off. The participant's task was to land on two legs in order to prevent joint overload.

CMJL – left leg counter-movement jump – a vertical jump similar to CMJR, but performed on the left leg.

SPJ – a vertical jump which is performed with a 3–4 step run-up before the take-off. The participant's task was to take off and land on the platform.

The participants were asked to jump as high as possible in each trial. There were 5-second breaks between each ACMJ, CMJJ, CMJR, CMJL jump and 1 min breaks between the SPJs. There was also 1-minute break between each series of jumps as well. The jump with the highest elevation of the body's COM was chosen for statistical analysis.

Isometric muscle strength (maximum joint torque)

The maximum joint torque of the flexors and extensors of the knee were measured under isometric conditions (velocity = 0 deg·s^{-1}) using a special torque meter (Institute of Sport, Poland; type TBK2-PM, lower limbs and trunk). The measurements for the hamstring and quadriceps were carried out in a sitting position. The knee joints were bent at 90°. The participants were stabilized at the level of the anterior superior iliac spines and thighs, with the upper extremities resting on the chest. The maximum extension of the knee joint was defined as 0°. The axis of rotation during joint torque measurements corresponded to the axis of rotation of the torque meter. Joint torques of the right and left limb were measured separately, with flexion followed each time by extension. The participants were instructed to develop possible maximal voluntary contraction (MVC).

Force sense in isometric conditions

After the assessment of maximum flexion and extension, the results were used to calculate the values for force sense testing. Fifty percent of the maximal MVC was set as a value of target force, and then the participants' task was to exert the handle of the dynamometer, at the same time receiving visual feedback. Once the target torque was achieved, the participants were instructed to remember the level of torque that was applied. The, the participants were asked to close their eyes (no visual feedback) and to reproduce the target force. The measurements were repeated twice. The difference between 50% of the maximum joint torque and the generated torque was used as a measure of force sensing ability. Similar methodology was described by Iwańska et al. [10].

In the next test, the participant attempted to develop a torque reproducing a sine course within the range of 10 to 50% of MVC performed using a special device ("JBA", Zbigniew Staniak, Poland) – type TBK2-PM (lower extremities and trunk). The measurements were carried out in a sitting position with

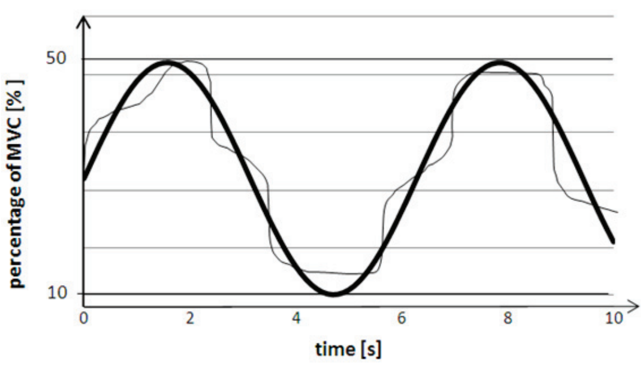

Fig. 1. Screen shot for the isometric force sensing test.
Legend: thick line – sine wave [$f_z(t)$],
thin line – line drawn by the cursor [$f_r(t)$]

the hip and knee joints bent at 90°, using the same stabilization procedures as at maximum torque measurements. The preset torque was shown as a still sine wave on a screen. The torque developed by the participants was visualized as vertical position of the cursor moving from left to right at the constant velocity. The participants' task was to place the cursor as close as possible to the sinusoid for 10 seconds (Fig. 1).

Two indexes were developed to evaluate force sensing abilities in this test:

1) absolute error – sum of areas created by the sinusoid and the line drawn by the cursor:

$$AE = \int | f_z(t) - f_r(t) | \, dt$$

where:

$f_z(t)$ – sine wave line,

$f_r(t)$ – sine line drawn by the cursor, moved by the participant.

2) absolute index – ratio of absolute error to area under the sine wave:

$$AI = \frac{\int | f_z(t) - f_r(t) | \, dt}{\int f_z(t) dt} \cdot 100\%$$

where:

$f_z(t)$ – sine wave line,

$f_r(t)$ – sine line drawn by the cursor, moved by the participant.

Isokinetic muscle strength (peak joint torque)

A Biodex dynamometer (Biodex S4 Pro, Biodex Medical Systems, Inc., Shirley, New York, USA) was used to evaluate the isokinetic strength of the hamstrings and quadriceps of the participants. Gravity correction was ensured for each limb before testing. Players were seated on the dynamometer chair at 85° with stabilization straps. The knee was set at 90° of flexion (0 deg = fully extended knee), according to the instruction manual by Biodex Medical Systems. The participants were instructed to extend and bend the tested leg as fast and as hard as they could over the entire range of motion (from 90 to 0°). Three maximal repetitions of extension and bending the knee were used for each angular velocity: 60 deg·s^{-1}, 180 deg·s^{-1} and 300 deg·s^{-1}. A 1-minute rest period was allowed between series. At each angular velocity, the trial with the highest peak torque was used for the statistical analysis. Peak torque ratios (H/Q ratio) for the hamstrings to quadriceps were calculated.

2.3. Statistical analysis

The analysis of variance (ANOVA) for repeated measures was used to compare the study results between the limbs and between the flexors and extensors. The significance of differences between means was evaluated *post hoc* with the Tukey's test. Distribution of all variables investigated was evaluated by the Kolmogorov–Smirnov test and Shapiro–Wilk test. None of the variables had a normal distribution. Spearman's rank correlation coefficient was used to evaluate correlations between all parameters. For the statistical analyses, the value of $\alpha = 0.05$ was considered as significant. All computations were performed with STATISTICA software™ (v. 12.0, StatSoft, USA).

3. Results

In table 1 mean values and standard deviations of peak muscle torques (PT) and average power (AP) obtained during flexion and extension of knee joint for individual velocities in isokinetic conditions and torques in isometric conditions (velocity = 0 deg·s^{-1}, MVC) are collected. Statistical differences were not found between the dominant and non-dominant limb for none of the angular velocities. Table 2 presents means and standard deviations for the quadriceps-to-hamstring torque ratio (H/Q). No statistically significant differences were found between the dominant and non-dominant limb. The hamstrings to quadriceps ratios differed statistically during the movement with different velocity. Statistically significant differences occurred in the case of the non-dominant limb ($F_{3,90} = 1,0$, $p = 0.001$, $\eta^2 = 0.25$) between the velocities of 300 deg s^{-1} and 60 deg s^{-1}, 300 deg s^{-1} and 0 deg s^{-1}, and 180 deg s^{-1} and 0 deg s^{-1}, and in the case of the dominant limb ($F_{3,90} = 22.43$, $p = 0.001$, $\eta^2 = 0.43$) between the velocities of 300 deg s^{-1} and 180 deg s^{-1}. Table 3 contains mean values with standard deviations for the maximal jump height, power and relative power developed by lower limbs during different types of jumps.

Table 1. Mean values (±SD) of peak torque (PT), average power (AP) at 300 deg·s^{-1}, 180 deg·s^{-1}, 60 deg·s^{-1} and 0 deg·s^{-1} and ANOVA results for the differences between the dominant and non-dominant limb

Variables	Dominant	Non-dominant	F	p	η^2
PTF_{300} [N·m]	95.9 ± 27.7	90.5 ± 24.7	0.65	0.42	0.01
PTF_{180} [N·m]	108.7 ± 17.4	107.7 ± 30.9	0.03	0.87	<0.01
PTF_{60} [N·m]	142.0 ± 20.4	144.7 ± 42.2	0.10	0.75	<0.01
PTF_0 [N·m]	167.7 ± 26.0	162.5 ± 28.4	0.56	0.46	0.01
PTE_{300} [N·m]	125.1 ± 33.5	133.3 ± 25.9	1.18	0.28	0.02
PTE_{180} [N·m]	169.7 ± 30.9	172.8 ± 27.6	0.17	0.68	<0.01
PTE_{60} [N·m]	239.4 ± 37.4	248.1 ± 34.6	0.89	0.35	0.01
PTE_0 [N·m]	315.3 ± 53.3	310.5 ± 43.6	0.15	0.70	<0.01
APF_{300} [W]	149.0 ± 91.5	131.5 ± 71.6	0.70	0.41	0.01
APF_{180} [W]	189.7 ± 47.0	190.6 ± 53.5	0.01	0.94	<0.01
APF_{60} [W]	105.8 ± 17.3	105.1 ± 20.7	0.02	0.88	<0.01
APE_{300} [W]	281.5 ± 108.0	293.0 ± 90.2	0.21	0.65	<0.01
APE_{180} [W]	306.6 ± 63.6	319.8 ± 62.8	0.68	0.41	0.01
APE_{60} [W]	164.8 ± 27.6	171.3 ± 27.2	0.87	0.36	0.01

F – flexion, *E* – extension.

Table 2. Mean values of (±SD) quadriceps to hamstrings torque ratio (H/Q) at 300 deg·s^{-1}, 180 deg·s^{-1}, 60 deg·s^{-1} and 0 deg·s^{-1} and ANOVA results for the differences between the dominant and non-dominant limb

Variables	Dominant	Non-dominant	F	p	η^2
H/Q_{300} [–]	0.79 ± 0.22	0.69 ± 0.19	3.35	0.07	0.05
H/Q_{180} [–]	0.65 ± 0.12[a]	0.63 ± 0.15	0.67	0.42	0.01
H/Q_{60} [–]	0.60 ± 0.10[a,b]	0.58 ± 0.11[a]	0.54	0.46	0.01
H/Q_0 [–]	0.54 ± 0.13[a,b]	0.53 ± 0.09[a, b]	0.35	0.55	0.01

[a] – means those that differ significantly from 300 deg·s^{-1} velocity, $p < 0.05$; [b] – means those that differ significantly from 180 deg·s^{-1} velocity, $p < 0.05$.

Table 3. Mean values (±SD) of the maximal jump height, power and relative power

Jumps	Height [cm]	Relative power [W·kg^{-1}]	Power [W]
ACMJ	39.93 ± 4.76	26.39 ± 5.31	3474.7 ± 1111.5
CMJ	46.87 ± 4.64	34.92 ± 4.40	4570.7 ± 1257.5
SPJ	57.11 ± 6.51	55.22 ± 12.52	7229.2 ± 2474.4
CMJL	28.92 ± 4.28	19.74 ± 6.06	2617.4 ± 1082.3
CMJR	28.67 ± 3.38	18.72 ± 3.98	2468.4 ± 751.5

ACMJ – akimbo counter-movement jump, CMJ – counter-movement jump, SPJ – a vertical jump with a run-up before the take-off, CMJR – right leg CMJ, CMJL – left leg CMJ.

No statistically significant differences between the dominant and non-dominant limbs were found during force sense tests (Table 4). A statistically significant correlation was found between the jump height of the jump without the arm swing (ACMJ) and with the arm swing (CMJ) and peak torque for the knee extensors during isokinetic condition with the exception of the movement performed with non-dominant limb at the speed of 60 deg·s^{-1} (Table 5). Peak power generated during jumps was significantly correlated with knee extensors force under isokinetic conditions. One exception was the lack of statistically significant correlation between the strength of the knee extensors in the dominant limb at 300 deg·s^{-1} with power generated during one-legged jump, both from the right and from the left leg and between strength of the extensors in the dominant limb at 60 deg·s^{-1} with power generated during one-legged jumps from the right limb (Table 6). The correlation between peak torques in the extensors developed under isometric conditions and jump height and power during the jump was not statistically significant, except for power developed during CMJL jump. No statistically significant correlation was found between the parameters of absolute error or absolute index in the force sense tests and muscle torques, jump height and power generated during the jump.

Table 4. Mean values (±SD) of absolute error (AE) and absolute index (AI) of dominant and non-dominant limb and ANOVA results for the differences between dominant and non-dominant limb

Variables	Dominant	Non-dominant	F	p	η^2
AEE [–]	16.2 ± 11.8	17.0 ± 13.0	0.07	0.80	<0.01
AEF [–]	18.2 ± 14.9	14.4 ± 11.5	1.25	0.27	0.02
AIE [%]	6.0 ± 2.3	5.6 ± 2.1	0.53	0.47	0.01
AIF [%]	5.9 ± 2.0	5.3 ± 1.3	1.7	0.2	0.03

F – flexion, E – extension.

Table 5. Spearman's correlation matrix between extension peak torque (PT) and height of the different jumps

Variables	Height [cm]				
	ACMJ	CMJ	SPJ	CMJL	CMJR
PTD_{300} [N·m]	0.50*	0.46*	0.26	0.20	–0.02
$PTND_{300}$ [N·m]	0.56*	0.53*	0.16	0.27	0.25
PTD_{180} [N·m]	0.66*	0.58*	0.24	0.36*	0.18
$PTND_{180}$ [N·m]	0.56*	0.61*	0.23	0.24	0.29
PTD_{60} [N·m]	0.52*	0.45*	0.26	0.39*	0.24
$PTND_{60}$ [N·m]	0.38*	0.35	0.20	0.27	0.18
PTD_0 [N·m]	0.23	0.05	0.19	0.34	0.09
$PTND_0$ [N·m]	0.26	0.17	0.16	0.32	0.03

D – dominant, ND – Non-dominant, PT_{300} – peak torque at 300 deg·s^{-1} velocity, PT_{180} – peak torque at 180 deg·s^{-1} velocity, PT_{60} – peak torque at 60 deg·s^{-1} velocity and PT_0 – peak torque at 0 deg·s^{-1} velocity; * – $p < 0.05$.

Table 6. Spearman's correlation matrix between extension peak torque (PT) and power of the different jumps

Variables			Power [W]		
	ACMJ	CMJ	SPJ	CMJL	CMJR
PTD_{300} [N·m]	0.45*	0.52*	0.36*	0.30	0.29
$PTND_{300}$ [N·m]	0.73*	0.79*	0.57*	0.47*	0.57*
PTD_{180} [N·m]	0.66*	0.70*	0.39*	0.49*	0.32
$PTND_{180}$ [N·m]	0.62*	0.69*	0.39*	0.45*	0.36*
PTD_{60} [N·m]	0.77*	0.82*	0.49*	0.57*	0.47*
$PTND_{60}$ [N·m]	0.50*	0.57*	0.24	0.28	0.17
PTD_0 [N·m]	0.23	0.27	0.25	0.41*	0.30
$PTND_0$ [N·m]	0.33	0.29	0.22	0.55*	0.32

D – dominant, ND – Non-dominant, PT_{300} – peak torque at 300 deg·s^{-1} velocity, PT_{180} – peak torque at 180 deg·s^{-1} velocity, PT_{60} – peak torque at 60 deg·s^{-1} velocity and PT_0 – peak torque at 0 deg·s^{-1} velocity; * – $p < 0.05$.

4. Discussion

The present study aimed to describe the biomechanical characteristics of dominant and non-dominant legs with an emphasis on knee extensors and flexors of soccer strikers. The main findings were that (a) a correlation between the maximum muscle torque in the knee extensors developed during the isokinetic contraction at all velocities and power in lower limbs developed during three types of jumps (ACMJ, CMJ, SPJ) was observed, (b) the jump height correlated with isokinetic muscle strength in knee extensor, but not with muscle torques developed in isometric contraction, (c) no differences were found between preferred and non-preferred legs during evaluation of strength and jumping abilities, and (d) no bilateral differences were observed in the force sense tests.

Strength abilities of the muscles of the knee joint are usually evaluated based on the results of measurements of muscle torques developed under isometric and isokinetic conditions [1], [6], [10], [12], [19], [24]–[27]. The results obtained are used to evaluate symmetry or asymmetry in the muscle groups studied [5], [6], [11], [17], effectiveness of training load [3], evaluation of the effect of fatigue [22] and post-exercise regeneration [1]. According to Kim and Hong [11], the likelihood of injuries caused by improper balance between antagonist muscles (flexors-to-extensors ratio) increases significantly if this value is lower than 0.6 at the velocity of 60 $deg \cdot s^{-1}$. A study by Fousekis et al. [6] examined soccer players with different competitive experience. The flexors-to-extensors ratio for the knee joint for each group at the velocity of 60 $deg \cdot s^{-1}$ ranged from 0.56 to 0.59. H/Q ratio obtained for other angular velocities (180 $deg \cdot s^{-1}$ and 300 $deg \cdot s^{-1}$) ranged from 0.61 to 0.63 and 0.68–0.71, respectively. The H/Q ratios obtained in this study were consistent with the results obtained by other authors [3], [6]. The H/Q ratios in the group studied increased significantly as the velocity increased. Similar phenomenon was described by Hewett et al. [9]. No statistically significant differences were observed between the dominant and non-dominant limbs in all measurements. This might suggest adequate distribution of load on both limbs.

During the game, strikers often have to demonstrate the precise ball control. An accurate pass or shot can be often of key importance. Kicking the ball with adequate force is started from the acceleration of the biokinematic chain of the lower limb. The use of information from, e.g., proprioceptors determines a skilful performance of the precise movement which is composed of development of a specific force by the muscles that move the limb. The measurements of force sense were aimed at evaluation of the ability of a player to develop a given muscle torque. The lack of statistically significant differences between the dominant and non-dominant limb during the measurements may suggest similar force-control abilities developed by muscles of both limbs. Similar findings were documented in studies by Iwańska et al. [10] and Rynkiewicz and Niewolna [20]. In a study by Iwańska et al. [10], the authors described reproduction of contraction in knee extensors and development of muscle torque in isometric contraction for 3 values of 30, 50 and 70% of MVC, respectively, in soccer players. These authors demonstrated that the athletes had the biggest difficulties with reproduction of 30% of MVC, whereas the smallest – for 70% of MVC. In a study by Rynkiewicz and Niewolna [20], where athletes were asked to develop the previously determined value of force during a measurement that mimicked the ball kicking motion, no bilateral differences were found for the attempt to reproduce the value of 50% of MVC. In light of these findings, the choice of the value of force in the range of 10 to 50 of MVC in our study was justified. No significant correlation was found between jumping abilities of athletes, peak power and muscle force and abilities to control muscular force of extensors and flexors of the knee.

The evaluation of physical abilities of players is often extended with measurements of jumping abilities and power. The measurements are typically made on force platforms or contact mats [2], [16], [19], [27]. Some authors note that the results of the measurements of jumping abilities and power in lower limbs represent a valuable diagnostic indicator since the method to perform them is very similar to the movement performed during sports competition [13]. Experienced French soccer players performed akimbo jumps to the following mean height: 41.56 ± 4.18 cm – the first league, 39.71 ± 5.17 cm – the second league, 43.93 ± 5.65 cm – amateurs [5], whereas younger (teenager) athletes from Japan – 47.0 ± 5.7 cm [4]. The jump height for French players was similar to elite Portuguese leagues, who raised their centre of gravity to the height of 40.4 ± 5.0 cm [19], 49 strikers from Iceland, with their jumping abilities of 39.4 ± 4.2 cm [2] and 23 Portuguese players who jumped to the height of 42.44 ± 4.04 cm [21]. In akimbo jumps, Polish striker reached 39.93 ± 4.76 cm. Despite different measurement methods (tests performed on contact mats), the results were similar to the findings presented in this study, with jump height calculated from the profile of ground reaction forces.

Many studies have attempted to evaluate correlations between muscle torques developed under conditions of isokinetic contraction and jump parameters. The present study found a correlation between peak torque developed by quadriceps muscles under isokinetic conditions and peak power developed during all types of jumps. Correlation coefficients for jumping with peak muscle torque in the knee extensors were significant for ACMJ and CMJ jumps. No significant correlation was found between jump height and isometric strength (MVC). This might have been caused by the fact that isometric muscle work is rarely used during actual playing on the field. Similar lack of relationships was described in the study by Thompson et al. [28]. The opinions about presence of relationships between peak force developed under isokinetic conditions and peak power are unequivocal. A study that examined 95 experienced soccer players from three different French adult leagues suggests the lack of presence of the above relationship [5]. Among 42 Japanese soccer players aged 13 to 15, this relationship was very strong [4]. A study by Menzel et al. [13], who examined 46 Brasilian professional players, found a moderate relationship between power an peak torque developed only at velocity of 180 deg·s^{-1} and 60 deg·s^{-1}, which is consistent with the results obtained in our study, with correlation for velocity of 300 deg·s^{-1} slightly lower than in other cases. These differences may result from the differences in the age of participants, place of birth, training methods and measurement methodologies. The first study was based on the measurements performed on Bosco contact mat, the second – on the evaluation of the rise of the centre of gravity using video recording technique whereas the third study employed measurements from the AMTI force plate.

The calculation of peak torque in relative values enabled the comparison of Polish strikers with soccer players from other countries. The results of strength abilities in the knee joint of Polish strikers were similar to the results recorded for the third-league Greek players [6]. Peak muscle torque in the knee extensors under isokinetic conditions of Polish strikers were slightly lower than those obtained for players from the South America [13]. On the contrary, the results obtained for Portuguese soccer players both before and after training [3] under isokinetic conditions at 60 deg·s^{-1} were slightly lower than for Polish players.

The findings of the present study were limited to the specific playing position under consideration. In soccer, there is a high specialization of players by position (goalkeepers, defenders, midfielders and strikers), which results in different anthropometric characteristics and muscle power [2], [18]. Thus, generalization of the findings on strikers on other playing positions should be done with caution. On the other hand, strength of this study was that it offered a complete evaluation of leg strength and power using both force plate and isokinetic dynamometry. These findings would be of great practical importance for both sports scientists and practitioners working with soccer players (e.g., coaches, fitness trainers and physiotherapists). All the tests performed are recommended to be utilized for monitoring of training process. Isokinetic strength measurements can be used in order to assess asymmetry, especially after injury incidents. Bilateral jumping tests sometimes are not sensitive enough to detect deficits resulting from strength differences between lower extremities. Since the sense of force does not correlate with other indices, it can be treated as independent motor ability reflecting precision of movement control.

5. Conclusions

A correlation between the maximum muscle torque in the knee extensors developed during the isokinetic contraction at all velocities and power in lower limbs developed during three types of jumps (ACMJ, CMJ, SPJ) was observed in Polish strikers. The jump height correlated with isokinetic muscle strength in knee extensor, but not with muscle torques developed in isometric contraction. No differences were found in Polish strikers between preferred and non-preferred legs during evaluation of strength and jumping abilities. Furthermore, no bilateral differences were observed in the force sense tests proposed in the study.

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