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Evaluation of selected biomechanical parameters in female team sports players

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The aim of this research was to evaluate the biomechanical parameters of lower limbs and their influence on height of vertical jump. The research was conducted on a group of females practicing basketball and volleyball. The following equipment was used during the experiment: a force plate by Kistler, a Biometrics electrogoniometer and a specially designed chair to measure static torque by OPIW Opole. The results indicated that the jumping abilities of the examined athletes were poor. No statistically significant correlations were observed between knee static torque and heights of vertical jumps: CMJ and DJ. The authors suggest modification of the McClymont index (RSI) to evaluate the selection of platform height during plyometric training. Such modification would enable better choice of loads and better training control of the subject.

Key words: *countermovement jump, drop jump, RSI, torque, vertical jump*

1. Introduction

In order to practice team sports, athletes must not only master a technique specific to the given sport discipline, but also need to be prepared in terms of motor control [1]. Coaches should be aware that, in order to train top class athletes they need to introduce training exercises which improve select motor abilities. Jumping abilities necessary in team sport should be developed in female athletes during their period of susceptibility to stimulation (approximate ages 10–11 and 14). Also, the individual development of each body should be considered [2].

Since team sports are continually changing, coaches need to follow the trends unfolding in the development of their respective sport discipline, and at the same time use new training methods based on scientific research. Such an instance might be the number of jumps performed by a basketball player during a game. In the 1980s, this number depended on the player's position and ranged from 30 to 70 jumps [3]. Twenty years later this number increased to 124–165 [4]. One should consider the fact that frequently combined and often repeated jumps need to be performed to a certain height. The height of the jump depends on the situation, for example, rebounding. Such situations lead to the necessity of achieving maximum jump height. NBA games broadcast in the 1990's made Polish players realize that their jumping abilities were often neglected in their training process.

The biomechanical parameters of lower limbs are related to the factors responsible for jump height, including: the use of elastic energy, the stretch–shorten cycle (SSC), the velocity of muscle contraction (stimulation of motor units) and their power (correctly identified as being the product of torque and angular velocity). As such, it is necessary to find a compromise between range and final velocity of push-off [5].

Exercises involving plyometric training are mainly used to develop muscle power (sometimes referred to as dynamic, or explosive force) [6]. One aspect of plyometric exercise is to stretch muscles prior to sudden and fast shortening. Sudden muscle contractions

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and extensions lead to the employment of additional motor units, which results in an increase of muscle power without the mass gain, and decrease of their excitability threshold. Hence muscles, when stretched, contract quicker. Plyometric exercises stimulate changes in the neuromuscular system. The effectiveness of plyometric training depends on resistance, velocity and range of movement in the exercises performed [6]. Research has confirmed that a significant increase in jump height can be attributed to plyometric training [7]–[9]. When introducing plyometric exercise, a coach should consider the level of the athlete's maturity and physical development. To do this, the following factors need to be determined: body litheness, range of lower limb and spine movement, body posture, ability to maintain balance, body weight, body composition and systematically measured speed-strength abilities. The intensity and amount of training require great individualization. Plyometric exercises ought to be intensive, however, the amount should not be high [7].

The lower limbs of people who do not practice sport, if measured, should be characterized by having the same level of strength in each. However, the situation is different in the case of athletes, especially those who practice in specific sport disciplines. Due to the specificity of a performed activity and the habitual usage of a stronger side of the body, it is possible to observe unequal development of the muscle corset. This phenomenon leads to greater loads being exerted on one side of the body, which is highly detrimental to health [11]. The increase of asymmetry in the lower limbs observed in team sport is common due to the asymmetry movements characteristic of the given sport. Different levels of asymmetry depend on the group examined (age, level of training, etc.) [12]. The ability to move symmetrically in sport increases a player's versatility and value, introduces an element of surprise against their opponent, and leads to correct physical development. Lateralization enables players to exercise not only the stronger side of their body but also the weaker one [13]. Even though strength has been widely researched, it remains difficult to determine the causes of asymmetry in muscles [12].

The aim of this research was to evaluate the level of selected biomechanical parameters which have a direct and indirect influence on jumping abilities. The authors were particularly interested in the relationship which occurs between the maximum knee static torque and the height of vertical jump, which has been examined in previous research [14]. The need to determine such correlations for team sport was reported in 1986 [15], and though the issue has since been discussed in many papers, none have offered conclusive results [16]–[26], only that the data suggests the existence of a positive correlation of this type [19], [21], [24]–[26].

2. Materials and methods

This research studied 20 athletes who play team sports (two groups of 10 practicing basketball and volleyball) and train at AZS AWF Wrocław, Poland. All the subjects were considered top athletes throughout tournaments of the Lower Silesia University League. The following mean characteristics (±SD) were measured: body height 172.4 ± 7.5 cm, body mass 63.2 ± 6.2 kg, age 21.5 ± 1.4 years. Research was conducted in the Laboratory of Biomechanical Analysis, which has been granted ISO (norm 9001:2009) certification. The players were informed about the purpose of the experimentation and provided written consent prior to participation. Before beginning the experimentation, the subjects were informed about the type of activities they would be performing and were encouraged to perform well.

Each subject performed 4 types of jumps: one countermovement jump (CMJ) and three drop jumps (DJ) from a platform situated at a height of 15, 30 and 45 cm, respectively. CMJ is a vertical jump where the jumper flexes the lower limbs and swings their arms upwards while jumping. DJ is an action wherein the subject drops to a flat surface from a specified height. After performing a jump, the subject's task was to land on a force plate. Each trial was performed three times. Only the best jump was taken into account in the analysis, considering the height, which was computed on the basis of the length of flight phase. A Kistler 9281B13 force plate with a sampling frequency of 200 Hz was used to record ground reaction forces. During experimentation, measurements were recorded by a computer which created numerical and graphic pictures of three components of ground reaction forces (Fx, Fy and Fz), torques and vectors of resultant forces (values, contact points and angles of this force). Ground reaction forces were measured by four piezoelectric sensors located at the four corners of the platform. The platform was connected to a Kistler 9863 A amplifier and an A/D converter. The platform was made of a material with a low-frequency of oscillation and solidly attached to the surface beneath to prevent movement. Electrogonometer SG Biometrics [Ltd] were fixed to the right knee of the subject to enable the observation of changes in angular values during the jump. BioWare® software was used to store measured data.

Additionally, the knee torques of each athlete were measured. Measurement was taken for knee joints at the angle of 75° for extensors and 30° for flexors. 0° was considered a completely extended knee joint. Selecting angle values enabled the identification of the highest possible static torque for both flexors and extensors. A UPR-01 B chair by OPIW Opole, with stabilizing straps and two measuring heads, was used for measurements. Due to the torquemeter, it was possible to directly measure a static torque without the need to measure arm length of the external force. The direct measurement of torque describes the work done by muscles better than the measurement of force due to the muscles work during rotation. Having taken a position in the chair (hips placed against the back of the chair), an athlete subject was strapped to it with stabilizing straps placed at the chest and thighs. The aim of this setup was to stabilize other body segments and to record the maximum torque of the selected muscle group. What is more, it aimed to eliminate the influence of adjacent muscle groups on the measured value of moment forces in the area of knee joints and to eliminate the influence of subjective ways of performing a movement to be measured. During the measurement process, the subjects' upper limbs were crossed over their chest. The torquemeter's axis of movement was adjusted to each subject individually so as to coincide with the lateral axis of the tested joint – 2,5 cm above the knee joint gap. Upon a signal to begin, the subject performed an isometric contraction in the sagittal plane. For each test, the order in which each leg was tested remained the same: right, then left. The trials were conducted three times for both legs and best results were recorded.

Statistical analysis was based on Pearson's r coefficient and Student's t-test at the level of $\alpha = 0.1$.

3. Results

The mean values (±SD) of maximum static torque of knee extensors and flexors (sum of both limbs) obtained by the subjects were 332.7 ± 23.9 Nm and 223.5 ± 27.9 Nm, respectively. Table 1 presents more detailed results separated by limb. The level of asymmetry between the static torque in the right and left limb was 14% for extensors and 10% for flexors. The level of asymmetry between the sum of static torque of right and left limb for flexors and extensors was 11%. The line between symmetry and asymmetry for the subjects in the examined age was 6% [12].

Table 1. The results of static torque (mean ±SD)

	Limb	
Static torque (Nm)	Right	Left
Knee joint extensors	170 ± 21	162 ± 15
Knee joint flexors	116 ± 15	108 ± 15

Table 2 presents the results of CMJ performance. Figures 1–4 present changes in ground reaction forces and in knee joint angle with time. The best results in reference to jump height were selected for graphs. Statistical analysis revealed no significant relationship between the knee static torque and the height of any type of vertical jump (Table 3). In addition, neither of the measured parameters had significant influence on the height of jumps (Table 4).

Due to the synchronization of registered data, it was possible to separate the time of contact during a DJ with the surface (amortization and push-off) into amortization time and push-off time. This allows the RSI index calculated from equation (1) (the numerator being the height of a jump in mm and denominator the time of amortization and push-off in ms) to be separated into two equations (2) and (3) [27],

$$\mathrm{RSI} = \frac{h}{t_{\mathrm{contact}}}, \tag{1}$$

Table 2. The results of vertical jumps performance (mean ± SD)

	F_o (N)	t_a (s)	t_o (s)	t_{a+o} (s)	α (°)	RSI	h (m)
CMJ	1601 ± 129	n/a	0.28 ± 0.05	n/a	82.2 ± 12	n/a	0.315 ± 0.04
DJ 15	2172 ± 287	0.15± 0.04	0.17 ± 0.02	0.32 ± 0.05	59.5 ± 17	0.93	0.307 ± 0.04
DJ 30	2480 ± 306	0.15 ± 0.02	0.16 ± 0.03	0.31 ± 0.05	61.8 ± 13.6	1.08	0.326 ± 0.05
DJ 45	3025 ± 497	0.14 ± 0.03	0.16 ± 0.03	0.3 ± 0.05	57.9 ± 19.2	1.14	0.328 ± 0.05

F_o – maximum push-off force, t_a – time of amortization, t_o – time of push-off, t_{a+o} – time of contact with the surface (amortization and push-off), α – maximum angle in knee joint during countermovement, RSI – McClymont index, h – height of a jump

$$\text{RSI (amortization)} = \frac{h}{t_{\text{amortization}}}, \quad (2)$$

$$\text{RSI (push-off)} = \frac{h}{t_{\text{push-off}}}. \quad (3)$$

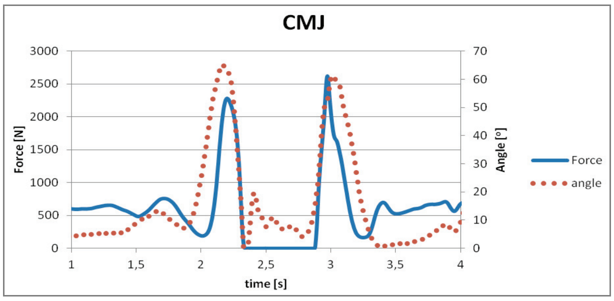

Fig. 1. Changes in ground reaction force and in knee joint angle in time for CMJ jump

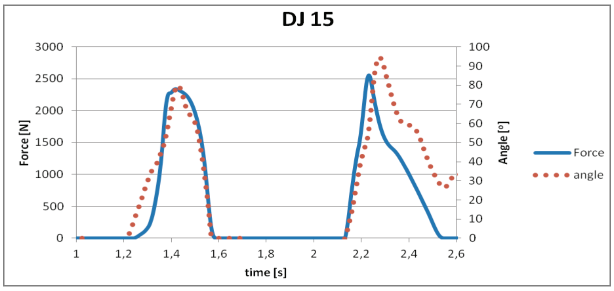

Fig. 2. Changes in ground reaction force and in knee joint angle in time for DJ jump of 15 cm platform

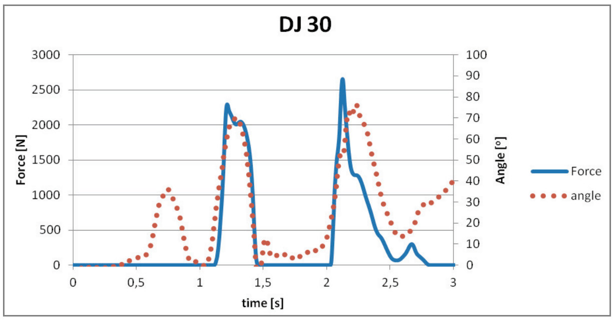

Fig. 3. Changes in ground reaction force and in knee joint angle in time for DJ jump of 30 cm platform

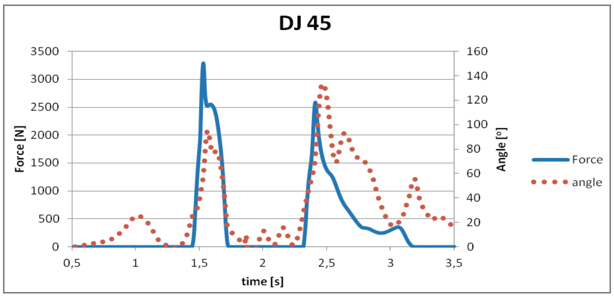

Fig. 4. Changes in ground reaction force and in knee joint angle in time for DJ jump of 45 cm platform

Table 3. Values of correlations between knee static torque (sum of both limbs) and the height of vertical jumps

	Static torque	
	Knee joint extensors	Knee joint flexors
h CMJ	–0.05	–0.16
h DJ 15	0.04	–0.05
h DJ 30	0.01	–0.06
h DJ 45	–0.07	–0.18

Table 4. Values of correlations between the height of vertical jumps and maximum push-off force (F_o), time of amortization (t_a), time of push-off (t_o), time of contact with the surface (t_{a+o}), maximum angle in knee joint during countermovement (α)

	F_o	t_a	t_o	t_{a+o}	α
h CMJ	0.17	n/a	0.15	n/a	0.04
h DJ 15	–0.21	0.06	0.08	0.08	0.19
h DJ 30	–0.39	0.15	0.3	0.31	0.15
h DJ 45	0.27	–0.14	–0.06	–0.13	0.01

Due to this separation, it was possible to precisely formulate the influence the height of the platform had on an athlete's parameters during plyometric training and determine whether it was suitably selected. After performing the task, the athlete can receive guidance related to the time of amortization after the drop or quicker push-off after the landing. This will enable them to correct the jump. There is no need to change the height of the platform when the player has an opportunity to correct one of the two elements mentioned. Thus, in the future it will be easier for a coach to select suitable training parameters. The value of the RSI index increases to maximum while the time of amortization and push-off decreases to minimum. Table 5 presents values of modified RSI indices, based on which it is easier to determine an athlete's reserves.

Table 5. Modified RSI indices for athlete who performed the highest jumps

	RSI of amortization	RSI of push-off
DJ 15	2.1	2.44
DJ 30	2.47	2.62
DJ 45	3.62	2.71

4. Discussion

Research conducted by Buśko [28] on a group of basketball players produced a lower maximum level of knee static torque than in the present research group. Other groups of female basketball players examined by the same author revealed similar results [29], [30]. We can draw a conclusion that the group examined in this paper represents a level of static torque that is close to that obtained in similar research groups.

The height of vertical jumps, time of contact with the surface in DJ and values of RSI index can be described as poor in comparison with other groups [7], [10], [27], [31]. It suggests that jumping abilities are not being developed in the training process and that this factor is neglected by coaches (despite its great intensity in team sport). The temporary introduction of plyometric training has a positive influence not only on jumping abilities, but also strength, speed and endurance [31].

No statistically significant relationships were observed between the knee static torque and the height of CMJ and DJ jumps. Similar results were presented in different papers related to this issue [16]–[18], [20], [22], [23]. These results are consistent with the authors assumptions and confirmed previous conclusions related to the matter [14]. Buśko wrote about a lack of statistically significant correlations between static torque and the parameters of vertical jumps in the basketball players examined [17], [18]. Similar conclusions can be formulated on the basis of other research conducted so far on football players [16] or students [22]. Significant correlations of this type should be perceived as random or as an effect of the specialization of a selected research group or practiced sport which may not be strictly related to jumping. Buśko et al. [19] examined a group of students (non-training) which revealed a significant relationship between knee static torque and the power developed in CMJ and its height. This seemed to confirm results obtained by Urbanik et al. [24]. Similar results were obtained by Trzaskoma [25], who examined a group of tennis players and other individual sports [26]. Positive correlations between torque and jump parameters were significant when the measurement was taken not in static but in isokinetic conditions [33], [34]. In sport disciplines where jumping similar to CMJ does not occur, its correct performance may cause problems [35]. Buśko and Nowak [20] confirmed the lack of increase in power and height of CMJ along with an increase in knee static torque in judokas. On the basis of the research conducted on football players, Król [23] observed that CMJ is not a good tool to control speed–strength training.

Three comparisons of the static torque of knee extensors and flexors of the right and left limbs revealed that the level of asymmetry obtained in the examined group was two times higher than normal [12]. The result is high, considering even the fact that groups of athletes who practice team sports are characterized by a certain level of asymmetry. It may indicate that the training performed by the players was highly oriented on the stronger side of the body with the absence of the same type of exercises performed by its opposite, weaker side.

5. Conclusions

1. There were no statistically significant correlations between measured knee torque and CMJ and DJ jump height in the examined group. This indicates that the measurement of torque cannot wholly define jumping abilities. At the same time it suggests that an increase in maximum strength abilities does not have a positive influence on jump height.

2. Measurements of biomechanical parameters related to vertical jumping in the examined athletes reflect their poor jumping abilities. This element was probably omitted during training or not enough attention was paid to it. Aside from this, the examined athletes obtained good results with regard to the measurement of static torque.

3. Due to the modifications of RSI index suggested by the authors it was possible to evaluate the amount of load and quality of exercise performed by the player. The modification was based on the measurement of angular changes in knee joints during plyometric training.

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