Analysis of the biomechanics of muscle activity of the lower limbs using a contact LED platform

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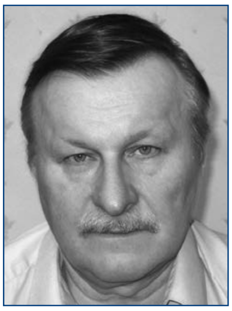

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Abstract

Objective of the study is to evaluate the biomechanical characteristics of the lower limb muscles using a contact LED track.

Methods and structure of the study. The study involved 215 high-level athletes (both genders, from masters of sports to masters of sports of international class), as well as young football players aged 16 to 18. The subjects performed three types of vertical jumps, pushing off with both feet: a jump from a half-squat position; a jump with a preliminary squat; a jump with a squat and using a swinging motion of the arms.

Results and conclusions. The analysis of the relationship between the height of jumps from a half-squat position and the indices of isokinetic dynamometry revealed that the correlation indices (r) between the height of jumps and the specific moments of force of the quadriceps femoris muscle, measured at an angular velocity of knee extension of 60 degrees/sec, vary from 0.5 to 0.9, depending on the specifics of the sport. The use of elastic properties of muscles by means of a preliminary squat and a reactive impulse from arm swing movements provides an increase in the height of jumps by an average of 30.4±8.6% compared to jumps performed from a half-squat position.

The highest values of the coordination coefficient (CC) are noted in athletes involved in cycling (CC> 15%). In football players and cyclists, the coefficient of elasticity (CE) exceeds the similar indicator in speed skaters and skiers (among men) by 2-3 times. In female athletes, the potential for elastic energy accumulation does not exceed KE<7%.

Keywords: *biomechanics of vertical jumps, elastic forces, reactive forces, coordination, reactivity index, biomechanical characteristics of lower limb muscles, contact LED track.*

Introduction. Vertical jumps are the most commonly used tests to assess lower limb muscle strength (LEM) and anaerobic power in various sports [4]. Jump height is used to assess the physical fitness of various population groups that differ in age, gender, and training [7]. In some sports, vertical jump is used to predict results [6, 9], and also allows determining the explosive power of the LEM muscles, the state of the elastic corset of the LE muscles, coordination abilities, speed-strength endurance, and the reactivity index [1, 5, 8]. The main methods for assessing the height of vertical jumps are calculations based on the force impulse recorded on a force platform or on the flight time [2].

Objective of the study is to assess the biomechanical characteristics of the lower limb muscles using a contact LED track.

Methods and structure of the study. The study involved 215 highly qualified athletes (MS-MSMK), as well as youth football players from various Moscow clubs (Table 1). The vertical jump height (H) was estimated by the flight time. Contact mats of the MuscleLab system (Ergotest Innovation AS, Norway) and an experimental sample of the contact LED track (ES-CDT) were used. The 90 cm wide bars were installed at a distance of 3 m from each other so that there were no foreign objects in the LED field [8].

Jump tests were conducted at training camps, as well as at the Federal State Budgetary Institution Federal Scientific Center of Physical Culture. During testing at the Federal State Budgetary Institution Federal Scientific Center of Physical Culture, the speed-strength manifestations of m. quadriceps were additionally estimated on the Biodex System 4 Pro dynamometer (Biodex Medical Systems Inc., USA) in the angular velocity range of 300-60 deg/s. The vertical jump height was estimated using the formula:

$$H = g\frac{t_{ПОЛ}^2}{8} = 1{,}226 * t_{ПОЛ}^2$$

where g is the acceleration of gravity, g=9.81 m/s^2; is the flight time (s).

The athletes performed three types of vertical jumps with a push-off with both legs: 1) from a half-squat position - knee joint angle of 90˚ - hands on the waist (PP); 2) vertical jump with a squat with hands on the waist (PSP); 3) vertical jump with a squat with arm swing (PSMR). The recovery of potential energy by the "elastic corset" of the NK muscles (elasticity coefficient - EC) was determined by the formula:

$$КЭ = \frac{(H_{ПСП} - H_{ПП})}{H_{ПП}} * 100$$

where Нпсп – height ПСП, cm; Нпп – height ПП, cm.

The coordination coefficient (CC) was determined by the formula:

$$КК = \frac{(H_{ПСМР} - H_{ПСП})}{H_{ПСП}} * 100$$

where $H_{псмр}$ – height ПСМР, cm; $H_{псп}$ – height ПСП, cm.

Results and conclusions. Five phases can be distinguished in the vertical jump: 1) the vertical component is equal to the body weight (initial position); 2) squat, when the subject flexes the NK at the joints - the vertical component (Rz) is less than the body weight; 3) push-off, when Rz initially increases and then decreases to zero upon separation from the support; 4) flight phase; 5) landing – Rz upon contact with the support increases sharply and exceeds the body weight by 2 or more times [1]. The second phase of the jump (squat) is performed in the eccentric mode, when due to rapid flexion in the NK joints, the parallel and sequential elastic structures of the muscles are lengthened ("elastic corset"). Additional elastic forces appear, as a consequence of this – the height of the PSP is on average higher than the height of the jump from the PP in men by 4.7±2.5 cm, in women by 1.9±0.8 cm (Fig. 1).

The maximum increase in the height of jumps with a squat in relation to the height of the jump from the PP position in male skiers is 9 cm and in female skiers – 2.8 cm. The highest height of the PSP is recorded in speed skaters 51.4±7.4 cm, the lowest in rowers and football players 39.3±4.4 and 36.2±4.7 cm, respectively. Similarly, in female speed skaters, the height of the PSP is 43±7.8 cm, the lowest value of the PSP height in female skiers is 26.5±3.5 cm (Fig. 1). If the jump is performed with an arm swing, the vertical support reaction in the push-off phase increases not only due to the elastic forces of the NK muscles in the squat phase, but also due to the reactive forces that arise during the arm swing, which contributes to the recruitment of additional motor units and, as a consequence, an increase in the push-off force impulse

Table 1. Subjects

Sport	Qualification	Gender, number of subjects, n	Age, years	Body length, cm	Body weight, kg
Cycling (track sprint)	HMS MSMK	M (n=6)	26±3	176±3,5	85,3±7,6
BMX cycling	MSMK MS	M (n=12)	23±4	182,4±6,3	81,0±5,5
		Ж (n=9)	22±5	164,4±3,8	62,3±7,7
Cross-country skiing	HMS MS of International Class MS	M (n=10)	23±4	179,8±6,2	72,5±6,7
		Ж (n=27)	17,7±4	168,0±3,4	60,6±4,7
Skating	HMS MS of International Class MS	M (n=37)	24±6	182,1±5,2	79,2±6,9
		Ж (n=33)	23±7	169,0±6,1	63,3±7,7
Rowing academic	MSMK MS	M (n=30)	22±6	192,3±8,2	89,2±11,2
Football	U16	M (n=51)	16±1	177,9±7,0	71,4±1,3

and jump height [1]. The highest VSR height was recorded in cyclists (BMX discipline) 59.8±10.0 cm, the lowest – in rowers and football players 45.0±5.4 and 43±5.7 cm, respectively. In women, the maximum VSR height is 48.1±7.9 cm (speed skaters), the lowest VSR 31.0±3.5 cm in ski racers (Fig. 1).

The vertical jump from the PP is performed with an amplitude in the knee joint of 85-90˚ (the initial angle is about 90˚, the final angle is 175-180˚). The jump height

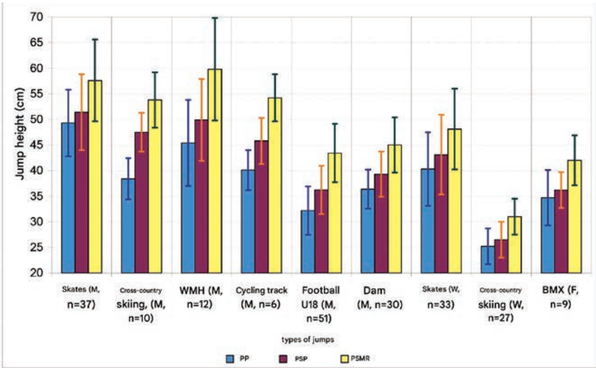

Fig. 1. Average value of the jump height in different sports

depends on the initial takeoff speed – the point at which the feet are torn off the support. Since the initial position of the subjects is standardized, the impulse of the repulsion force depends on the maximum force of the NK and the force gradient, the faster the athlete performs extension in the joints, the greater the vertical acceleration, and therefore the repulsion force. According to the electromyographic study, the main extensor muscles of the NK joints are involved in the PP: the gluteal group, the muscles of the anterior and posterior surfaces of the thigh and lower leg [1].

The univariate analysis of variance revealed reliable differences in the height of the jumps of the PP, PSP and PSMR depending on the type of sport. Therefore, for each sport, regression equations were calculated between the height of the jumps and the moments of m. quadriceps, recorded on an isokinetic dynamometer at angular velocities of 60-90 deg/s (M60 and M90, presented in Table 2). The type of regression equation was selected taking into account the coefficient of determination (R2). The highest statistical relationship was found between the moments of m. quadriceps, normalized to body weight and the height of the jump from a half-squat position. For example, for female speed skaters, the R2 values between the height of the jumps of the PP, PSP and PSMR and the moment of m. quadriceps are: 0.50; 0.43; and 0.45, respectively.

Fig. 2 shows the results of calculating the KE and CC using formulas (1), (2) and (3), respectively. The calculated coefficients of KE and CC in football players are 2 times higher than in speed skaters, which reflects the biomechanical features of the functioning of the NK motor apparatus in football conditions (the muscle "stretching-contraction" cycle): acceleration, changes in the direction of movement, martial arts and jumps. In speed skaters, the NK muscles work in the "isometry-concentric" mode with minimal accumulation of elastic forces (KE < 7% in both men and women) [3].

The NK muscles of football players work in the "stretching-contraction" mode, which has a positive effect on the ability to store elastic energy by the NK tendon-ligament apparatus, KE = 13.2% (Fig. 2). The ability to store elastic energy in women does not exceed KE < 7%. The highest level of coordination was recorded in male cyclists (BMX discipline). Compared to other sports, BMX cyclists use reactive forces arising during the PSM better than other athletes, which is confirmed by the high coefficient of CC = 20% (Fig. 2). In women, the maximum CC> 15% was recorded in cross-country skiing and BMX (Fig. 2).

Table 2. Regression equations for calculating normalized moments on the body weight of the knee extensor muscles depending on the height of the jump from a half-squat

Sport	Type of equation	Height, cm; M±m (median)	Correlation coefficient (r)
Cycling, sprint track (n=6), M	M60/ weight =1,2435*exp (0,0231**H*)	39,9±4,0 (38,5)	0,92
Cycling BMX, (n=12), M	M60/ weight =1,7619*exp (0,0121**H*)	40,8±8,9 (42,0)	0,72
Cycling BMX, (n=9), W	M60/ weight =2,0304*exp (0,008**H*)	41,1 ±8,8 (42,0)	0,56
Cross-country skiing (n=10), M	M60/ weight =0,701*exp (0,0037**H*)	38,0±3,5 (38,3)	0,77
Football (n=51), M	M90/ weight =1,8683*exp (0,0142**H*)	32,5±3,8 (31,9)	0,57
Speed skating, (n=37), M	M60 =120,1*exp (0,0161**H*)	49,3±6,5 (49,0)	0,65
Speed skating, (n=33), F	M60/ weight =1,5669*exp (0,0174**H*)	40,3±7,2 (40,4)	0,71

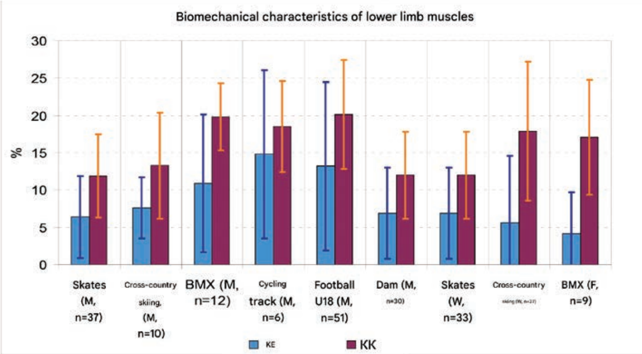

Fig. 2. Biomechanical characteristics (coefficients CE and CC) of the muscles of the lower extremities, calculated for vertical jumps

Conclusions. The contact LED track, which allows recording the height of upward jumps, is an accessible, inexpensive and informative tool that allows assessing various biomechanical characteristics of the NK muscles, for example, the maximum strength of the knee extensor muscles, the storage of elastic energy by the elastic corset of muscles, the level of coordination.

Comparison of the height of jumps from a half-squat with the results of isokinetic dynamometry showed that the correlation coefficients between the height of jumps and the normalized moments of m. quadriceps at an angular velocity of 60 deg/s in various sports are in the range of $0.5<r<0.9$.

In men, the jump height when using the elastic properties of muscles (due to the squat) and reactive forces (due to the arm swing) in relation to jumps from a half-squat increases by 16.8%, 40.1%, 31.7%, 35.2%, 34.9%, 23.7% (speed skaters, cross-country skiers, cyclists, football players, rowers, respectively).

In women, the elastic and reactive forces that arise when squatting and swinging arms increase the jump height by: 19.4%, 23.0% and 21.0% (speed skaters, cross-country skiers and BMX cyclists, respectively).

High CC>15% were recorded in cyclists (men and women, Fig. 2). The "stretch-contraction" mode of muscle-tendon complexes has a positive effect on the ability to store elastic energy. Thus, in football players and cyclists (track and BMX disciplines) this potential is 2-3 times higher than in speed skaters and skiers (men). In women, the potential for storing elastic energy in the muscles of the lower extremities is <7%.

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