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BIOMONITORING OF ELITE WOMEN TRIPLE-JUMPERS' ELASTIC FORCE

INTRODUCTION

Triple jump is a complex technical track and field discipline, structured from the run-up phase and three consecutive jumps. The result is defined mostly with the speed of run-up and optimal proportion of individual jump lengths (Hay, 1992; Grahman-Smith, Lees, 1994; Jurgens, 1996). Each of the partial jumps represents specific motor task with particular characteristics and tasks, which athletes must fulfil in order to successfully execute triple jump. In keeping with biomechanical and neuromuscular principles of triple jump, one of the key areas is diagnostics in the area of strength in female and male triple jump athletes.

The results of some studies (Bosco, 1992; Bosco et al., 1995; Zatsiorsky, 1995; Komi, 2000; Joshua et al., 2011) showed that drop jumps from various heights are the best indicator of special take-off strength. Experimental procedure in present study employed 25- and 45-cm high drop jumps, which generate eccentric – concentric muscular modulation. This stretch – shortening cycle (SSC) is a result of stretching due to the external forces and shortening of muscles in the second phase (Komi and Gollhofer, 1997; Nicol et al., 2006). In eccentric phase a certain amount of elastic energy is stored in muscular-tendon complex, which can be spent in the second phase. A part of elastic energy accumulated in a muscle is available only for a definite time, depending on a life span of cross bridges in a muscle, which is between 15 and 120 milliseconds (Cavagna, Cittero, 1974; Cavagna, 1977; Bobbert et al., 1987; Bobbert & van Ingen Schenau, 1988; Komi and Gollhofer, 1997). The efficiency of stretch – shortening cycle (SSC) depends also on the time of switch from eccentric to concentric contraction. The longer is the switch, the lesser is the efficiency of contraction. Besides magnitude and velocity of changes in muscle length and the time of switch from eccentric to concentric phase, preactivation of muscles is also very important for the efficiency of stretch – shortening cycle (Nicol et al., 2006).

The purpose of present study was to find the most important kinematic and dynamic parameters of four female elite athletes in drop jumps from 25- and 45-cm heights. Tests differentiated in starting height. It could be assumed that in drop jump from 45-cm height the force of muscle stretching will be larger in eccentric phase, which will consequently lead to integration of elastic and chemical energy in concentric phase of take-off. As larger amount of accumulated elastic energy will be carried over to concentric phase of take-off, and assuming that short contact time will be accomplished, hypothetically higher vertical jumps can be expected. Both tests are important diagnostic indicators of the degree of take-off strength in triple jump athletes of both genders.

METHODS

The sample of measured subjects included four female triple jump athletes (age 26.3 ± 4.2 years, body height 171.3 ± 9.6 cm and body weight 65.2 ± 4.1 kg. Average triple jump result of athletes was 13.74 ± 1.4 m. Measured subjects performed drop jumps from 25- and 45-cm height in a random order. When performing jumps, the hands were fixed at hip height. Each jump was repeated three times, the best result was included in the study. A system of 9 CCD cameras type SMART-e 600 with 20 Hz frequency and 768 x 576 pixels resolution was used in order to achieve 3-D kinematic analysis of vertical jumps. Analysis of kinematic parameters was carried out with the use of BTS SMART Suite programme. A dynamic model has been defined with a system of 17 infra-red sensitive marking points. Calibration of space has been performed with a system Thort2. On the basis of kinematic model of analysis the following parameters of drop jumps from 25- and 45-cm height have been examined: take-off height, duration of take-off phase, duration of eccentric phase, duration of concentric phase, take-off velocity, take-off velocity and eccentric phase. Dynamic parameters of drop jumps were collected with the use of two independent tensiometric force plates. The frequency of data collection was 1000 Hz. The surface reaction force was measured unilaterally and bilaterally. Analysis included the following dynamic parameters: maximal surface reaction force with left and right leg, total impulse of surface reaction force, the impulse of force with left and right leg.

RESULTS AND DISCUSSION

The results in Tables 1 and 2 reveal that the athletes have achieved in average better results in drop jump from 45-centimetre height (45.22 ± 4.65 cm).

Table 1. *Kinematic and dynamic parameters of 25-cm drop jump*

Parameter	**Unit**	**A1**	**B1**	**C1**	**D1**	**Mean**	**SD**
DJ25H	cm	49.6	40.4	46.4	38.6	**43.75**	**5.13**
DJ25CONTACT	ms	155	135	183	174	**161.75**	**13.44**
DJ25FL	N	1382	1539	753	1937	**1402.75**	**492.13**
DJ25FR	N	1354	1474	893	1752	**1368.25**	**358.00**
DJ25IMPR	Ns	141	118	88	139	**121.50**	**24.63**
DJ25IMPL	Ns	146	127	103	103	**132.25**	**22.38**
DJ25VEL	ms^{-1}	2.88	2.56	2.99	2.99	**2.77**	**0.19**
DJ25DOWN	ms^{-1}	-2.68	-2.26	-2.86	-2.86	**-2.55**	**0.27**

Key: DJ25H-height of jump, DJ25CONTACT- total contact time, DJ25FR-maximal force (right leg), DJ25JFL-maximal force (left leg), DJ25IMPR- force impulse (right leg), DJ25IMPL- force impulse (left leg), DJ25VEL- velocity of take-off, DJ25DOWN- eccentric velocity.

Table 2. *Kinematic and dynamic parameters of 45-cm drop jump*

Parameter	Unit	A1	B1	C1	D1	Mean	SD
DJ45H	cm	51.0	42.2	46.9	40.8	**45.22**	**4.65**
DJ45CONTACT	ms	151	143	172	170	**159.00**	**11.03**
DJ45FL	N	1482	1601	830	2025	**1484.50**	**494.66**
DJ45FR	N	1439	1504	893	2017	**1463.25**	**459.73**
DJ45IMPR	Ns	147	134	93	147	**130.25**	**25.57**
DJ45IMPL	Ns	152	134	105	165	**139.00**	**25.98**
DJ45VEL	ms^{-1}	2.92	2.71	3.05	2.76	**2.86**	**0.15**
DJ45DOWN	ms^{-1}	-3.09	-2.83	-3.21	-2.73	**-2.96**	**0.22**

Key: DJ45H- height of jump, DJ45CONTACT- total contact time, DJ45FR- maximal force (right leg), DJ45JFL- maximal force (left leg), DJ45IMPR- force impulse (right leg), DJ45IMPL- force impulse (left leg), DJ45VEL- velocity of take-off, DJ45DOWN- eccentric velocity.

The difference between the 25- and 45-centimetre drop jumps was 1.47 cm. The best result (51 cm) was achieved by a female athlete A, who also possessed the best triple jump result. The average value of contact time has been in measured subjects lower in drop jump 45-cm height. Duration of eccentric phase does not vary between the jumps; however, the difference in concentric phase is apparent. Namely, in drop jump from 45-cm height, the duration of concentric phase is shorter by more than 3 milliseconds. Surface reaction force was in drop jump from 45-cm height recorded at 2947 ± 366 N, compared to 2770 ± 411 N in drop jump from 25-cm height. Separate results of surface reaction force measured with bipedal force platform revealed that the measured subjects developed larger force with a left (dominant) leg in drop jumps from both heights. The difference in surface reaction force between left and right leg came to 34 N in drop jump from 25-cm and 21 N from 45-cm height.

A purpose of drop jumps is to reduce the duration of amortisation, which generates optimal switch from eccentric into concentric contraction. If an eccentric contraction is not followed quickly enough by a concentric one, it leads to a loss of elastic energy, which has been stored in cross bridges of muscles. In a phase of muscle and tendon elongation (prestrech), the main part of elastic energy is stored in serial elastic muscle elements – aponeurosis, tendons and cross bridges (Bobbert et al., 1977; Bobert, van Ingen Schenau, 1988). A part of elastic energy is available only for 15 - 100 milliseconds (Cavagna and Cittero, 1974; Bosco, 1979; Komi and Gollhofer, 1997). Amount of elastic energy stored depends also on the force of muscle stretch and muscle-tendon complex stretch. Rigidity of both systems is therefore important. Triple jump athletes in particular develop higher rigidity in muscles (m. gastrocnemius) than in the Achilles tendon (Zatsiorsky, 1995). It is a known fact that muscle-tendon complex in conditions of higher velocity of stretch - shortening cycle can store larger amount of kinetic energy in a form of elastic energy (Bobbert, van Soest, 2000; Komi, 2000). Generating elastic energy also means shorter contact times, which is a decisive factor for maintaining horizontal velocity in triple jump. In longer contact times with a surface (more than 200 milliseconds), a part of absorbed elastic energy transforms into heat energy (Zajac, 1993; Komi, 2000; Komi, Nicol 2000). Studies have revealed (Perttunen et al., 2000; Panoutsakopoulos, Kollias, 2008) that in the female elite triple jump athletes the contact times vary in different jumps (hop, step, jump) from between 120 to 185 milliseconds. Similar results have also been revealed in drop jumps on a sample of female athletes in the present study.

According to the results of the present study, it can be concluded that in 45-cm drop jump a sample of female triple jump athletes achieved larger vertical height (45.22 ± 4.65 cm), shorter contact times (159 ± 11.03 ms), higher vertical velocity of take-off (2.86 ±0.15 ms^{-1}) and larger bilateral surface reaction force (2947±27.88 N) at identical amplitudes in knee and ankle joint. In 45-cm drop jump, athletes developed 7.01% larger surface reaction force than in 25-cm drop jump. Individual results showed unilateral surface reaction force of the left (dominant) leg at 1402 ± 492 N and of the right leg at 1368 ± 358 N. The difference in maximal surface reaction force between dominant and non-dominant leg was 34 N, whereas in the 45-cm drop jump it was only 21 N.

Drop jumps from 45-cm height require larger eccentric velocity in amortisation phase, which amounted to - 2.96 ± 0.22 ms^{-1} in comparison to -2.55 ± 0.27 ms^{-1}. Apparently, female elite jumpers use a strategy of jumping with a fast stretch – shortening cycle. Namely, only a fast switch of eccentric contraction into a concentric one whilst using the stretch reflex allows an efficient transfer of elastic energy from first into second phase of the take-off action. This has been clearly manifested with a vertical velocity of take-off in concentric phase of a jump. In 45-cm drop jumps female jumpers achieved vertical take-off velocity of 2.86 ± 0.15 ms^{-1}, compared to 2.77 ± 0.19 ms^{-1} in 25-cm drop jumps.

Drop jumps are extremely important training tools in male and female triple jump athletes. They are used for improving the function of eccentric-concentric muscular functioning in lower extremities. The present study has revealed that drop jumps from 45-cm height provide the best effects in development of take-off strength in condition of eccentric-concentric contractions.

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The aim of the study was to analyse kinematic and dynamic parameters of elastic force of elite women triple jumpers. The elastic force, in combination with horizontal velocity, is the most important factor of success in a triple jump. To establish the elastic force we conducted a biomechanical analysis, using drop jumps from the heights of 25 and 45 cm. The basic kinematic and dynamic parameters were registered using the Kistler Type 9286 bipedal force platform which had been synchronised with a 3D infra-red kinematic system CCD Smart – 600 E. Based on kinematic and dynamic analysis we can establish that the results in drop jumps are generated by the following variables: jump height, contact time, vertical velocity of takeoff, force impulse and the eccentric phase.

***Key words**: diagnostics, dynamics, kinematics, triple jump, elastic force, drop jumps.*