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Original research article

THE BIODYNAMIC ANALYSIS OF DROP JUMPS IN FEMALE ELITE ATHLETES

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Abstract. *The purpose of the study was a biodynamic analysis of kinematic and dynamic parameters in two types of drop jumps (from a height of 25 cm and 45 cm). The sample of measured participants included four female elite triple jump athletes with their best results varying from 13.33 to 15.03 meters. Kinematic and dynamic parameters were calculated with the use of a bipedal tensiometric force plate, which was synchronized with nine CCD cameras. In the drop jump from a height of 25 cm, the measured participants achieved the following results: height of the jump 43.37 ± 5.39 cm and surface reaction force 2770 ± 411 N. In comparison, the results in the drop jump from a height of 45 cm were: height of the jump 45.22 ± 4.65 cm and surface reaction force 2947 ± 366 N. The vertical velocity of the take-off in the 25 cm drop jump was 2.77 ± 0.19 ms^{-1} and in the 45 cm drop jump 2.86 ± 0.15 ms^{-1}.*

Key words: *track and field, biomechanics, drop jumps, diagnostics.*

INTRODUCTION

The 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 the run-up and optimal proportion of individual jump lengths (Hay, 1992; Grahman-Smith & Lees, 1994; Jurgens, 1996). Each of the partial jumps represents a specific motor task with particular characteristics and tasks, which athletes must fulfil in order to successfully execute a triple jump.

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In keeping with the biomechanical and neuromuscular principles of the 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, Vittori, & Matteuci, 1995; Zatsiorsky, 1995; Komi, 2000; Joshua, Weinhandl, Smith, & Dugan, 2011) showed that drop jumps from various heights are the best indicator of special take-off strength. The experimental procedure in the current study included drop jumps from 25 cm and 45 cm, which generate eccentric-concentric muscular modulation. This stretch-shortening cycle (SSC) is a result of stretching due to the external forces and the shortening of muscles in the second phase (Komi & Gollhofer, 1997; Nicol, Avela, & Komi, 2006). In the eccentric phase a certain amount of elastic energy is stored in the 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 the life span of cross bridges in a muscle, which is between 15 and 120 milliseconds (Cavagna, & Cittero, 1974; Bobbert & van Ingen Schenau, 1988; Komi & Gollhofer, 1997). The efficiency of the stretch-shortening cycle (SSC) also depends on the time of the switch from an eccentric to a concentric contraction. The longer the switch, the smaller the efficiency of the contraction. Besides the magnitude and velocity of changes in muscle length and the time of the switch from the eccentric to the concentric phase, the pre-activation of muscles is also very important for the efficiency of the stretch-shortening cycle (Nicol et al., 2006). Pre-activation is defined with the first contact of the foot with the surface and is manifested mainly in sprints, horizontal and vertical jumps. Pre-activation prepares muscles for stretching and is manifested in the number of joined cross bridges and changes in the excitation of ά-motor neurons.

The aim of the current study was to find the most important kinematic and dynamic parameters of four female elite athletes in drop jumps from a height of 25 cm and 45 cm, i.e., to examine the kinematic and dynamic parameters and find an optimal height of the drop jumps, which will have the largest effect on the special strength of female triple jump athletes. The tests differed in starting height. It could be assumed that in a drop jump from a height of 45 cm the force of the muscle stretch will be larger during the eccentric phase, which will consequently lead to the integration of elastic and chemical energy during the concentric phase of take-off. As larger amounts of accumulated elastic energy will be carried over to the 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 the triple jump of athletes of both genders.

THE METHOD

The sample of measured participants 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). The average triple jump result of the athletes was 13.74 ± 1.4 m, while the best jumper had a result 15.03 m, achieving 6th place at the 2008 Beijing Olympic Games). The measured participants performed drop jumps from a height of 25 cm and 45 cm in random order (see Figure 1).

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 (BTS Bioengineering, Padua) with a frequency of 20 Hz and 768 x 576

Fig. 1. The measurement protocol for the kinematic and dynamic parameters of the 45 cm drop jump.

pixel resolution was used in order to achieve a 3-D kinematic analysis of the vertical jumps. An analysis of kinematic parameters was carried out with the use of the BTS SMART Suite program. A dynamic model has been defined with a system of 17 infra-red sensitive marking points (head, shoulders, upper arms, forearms, torso, hips, thighs, calves and ankles). The calibration of space was performed with using a Thort2 (BTS SMART-D) system. On the basis of the kinematic model of analysis the following parameters of the drop jumps from a height of 25 cm and 45 cm were examined: take-off height, duration of the take-off phase, duration of the eccentric phase, duration of the concentric phase, take-off velocity, and the eccentric phase.

Dynamic parameters of drop jumps were collected with the use of two independent tensiometric force plates (Kistler Wintherthur Switzerland, Type 9286A, 600 x 400). The frequency of data collection was 1000 Hz. The surface reaction force was measured unilaterally and bilaterally (see Figure 2).

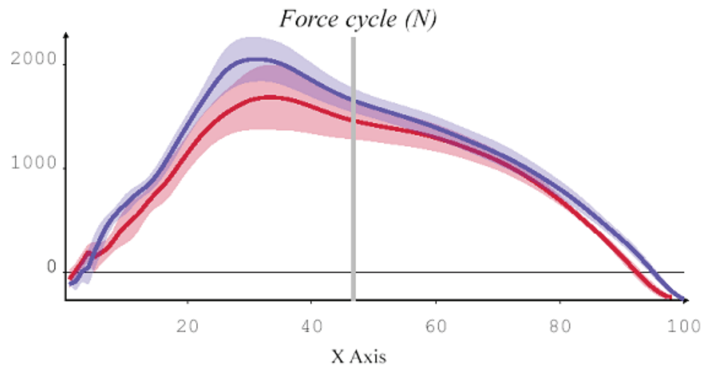

Fig. 2. Bilateral surface reaction force (L, R) in 45 cm drop jumps.

The analysis included the following dynamic parameters: maximal surface reaction force with the left and right leg, the total impulse of surface reaction force, the impulse of force with the left and right leg. A method of inverse dynamics has been used to calculate Power (P) in the hip, knee and ankle joints and to normalize it to the body weight (Wkg^{-1}, see Figure 3). The calculation has been carried out according to the following formula: Power (P. t) = M (t) x ω (t); (Vaughan, Davis, & O' Connor, 1999). The statistical analyses of the results was carried out with the use of SPSS computer program.

RESULTS AND DISCUSSION

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

Table 1. The kinematic and dynamic parameters of the 25 cm drop jump.

Parameter	Unit	A	B	C	D	Mean	SD
DJ25H	cm	49.6	40.4	46.4	38.6	43.75	5.13
DJ25TIMECON	ms	88	83	108	80	89.75	12.60
DJ25TIMEECC	ms	67	52	75	94	72.00	17.49
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 the jump, DJ25TIMECON – duration of the concentric phase of the take-off, DJ25TIMEECC – duration of the eccentric phase of the take-off, 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. The kinematic and dynamic parameters of the 45 cm drop jump.

Parameter	Unit	A	B	C	D	Mean	SD
DJ45H	cm	51.0	42.2	46.9	40.8	45.22	4.65
DJ45TIMECON	ms	83	84	100	79	86.50	9.25
DJ45TIMEECC	ms	68	59	72	91	72.50	13.47
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 the jump, DJ45TIMECON - duration of the concentric phase of the take-off, DJ45TIMEECC – duration of the eccentric phase of the take-off, 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 the take-off, DJ45DOWN - eccentric velocity.

The difference between the 25 cm and 45 cm drop jumps was 1.47 cm. The best result (51 cm) was achieved by female athlete A, who also achieved the best triple jump result. The average value of the contact time in the measured participants was lower in the drop jump from a 45 cm height. The duration of the eccentric phase does not vary between the jumps; however, the difference in the concentric phase is apparent. Namely, in the drop jump from a height of 45 cm, the duration of the concentric phase is shorter by more than 3 milliseconds. The surface reaction force for the drop jump from a height of 45 cm was recorded at 2947 ± 366 N, compared to 2770 ± 411 N in the drop jump from a height of

25 cm. The separate results of surface reaction force measured with a bipedal force platform revealed that the measured participants developed a larger force with the left (dominant) leg in drop jumps from both heights. The difference in the surface reaction force between the left and right leg came to 34 N in the drop jump from 25 cm and 21 N from 45 cm.

The purpose of drop jumps is to reduce the duration of amortization which generates the optimal switch from the eccentric into the concentric contraction. If an eccentric contraction is not followed quickly enough by a concentric one, it leads to a loss of elastic energy, which is stored in the cross bridges of muscles. During the phase of muscle and tendon elongation (the prestrech), the main part of elastic energy is stored in serial elastic muscle elements – aponeurosis, tendons and cross bridges (Bobert & van Ingen Schenau, 1988). A part of the elastic energy is available only for 15-100 milliseconds (Cavagna & Cittero, 1974; Komi & Gollhofer, 1997). The amount of elastic energy stored also depends on the force of the muscle stretch and muscle-tendon complex stretch. The 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 the muscle-tendon complex in conditions of higher velocity of the stretch-shortening cycle can store larger amounts of kinetic energy in the form of elastic energy (Bobbert & van Soest, 2000; Komi, 2000). Generating elastic energy also means shorter contact time, which is a decisive factor for maintaining horizontal velocity in the triple jump. In longer contact times with the surface (more than 200 milliseconds), a part of the absorbed elastic energy transforms into heat energy (Zajac, 1993; Komi, 2000; Komi & Nicol, 2000). Studies have revealed (Perttunen, Kyrolainen, & Komi, 2000; Panoutsakopoulos & Kollias, 2008) that among female elite triple jump athletes 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 current study.

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

Drop jumps from a height of 45 cm require larger eccentric velocity during the amortization phase, which amounted to - 2.96 ± 0.22 ms^{-1} in comparison to -2.55 ± 0.27 ms^{-1} (see Figure 3).

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

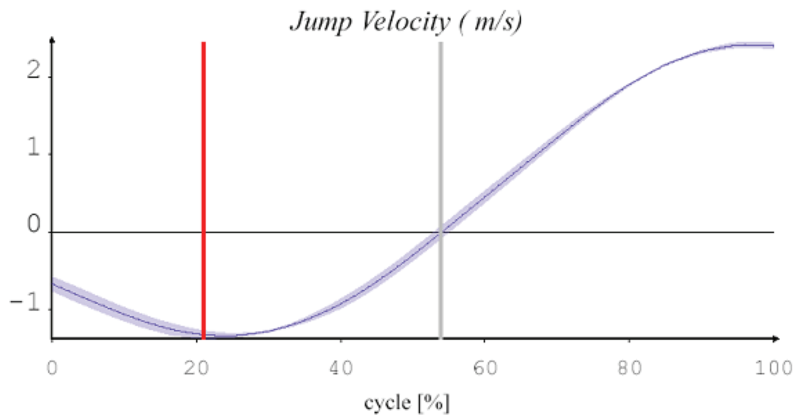

Fig. 3. Eccentric and concentric velocity in the amortization phase, the 45cm drop jump.

With the help of inverse dynamics strength of the joints has been observed in hips, knees and ankles in 25 cm and 45 cm drop jumps. Strength has been normalized according to the body mass of female athletes (Wkg^{-1}). In 25 cm and 45 cm drop jumps female athletes showed the highest values in the strength of the knee joint, then ankle and hip joints (see Figure 4).

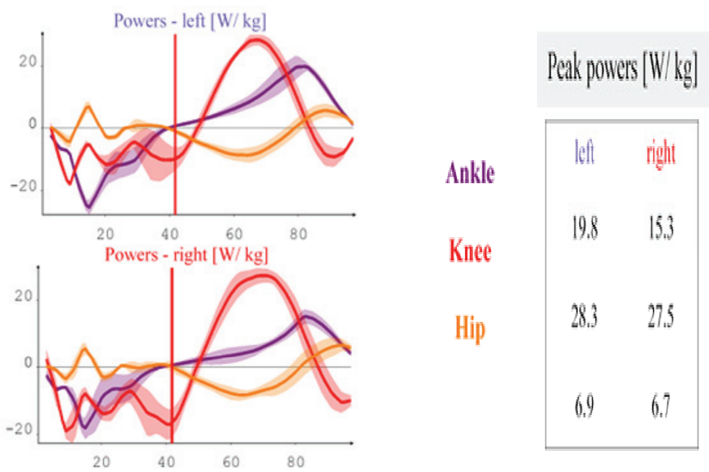

Fig. 4. Joint strength (P) in the hips, knees and ankles / normalized in terms of the body mass (Wkg^{-1}) – drop jump 45, according to Vaughan et al., 1999.

The average value of bilateral joint strength was 55.8 Wkg^{-1}. A strong symmetry has been revealed between dominant and non-dominant legs. Unilateral joint strength of the knee was 28.3 Wkg^{-1} in the left leg and 27.5 Wkg^{-1} in right leg for the 45 cm drop jump. A total joint strength of all three joints in female athletes amounted to 104.5 Wkg^{-1} in the 45 cm drop jump and to 88.5 Wkg^{-1} in the 25 cm drop jump. These values reveal the degree of loading of the lower extremities, which are similar to competition conditions for the female triple jump (Hay, 1992; Perttunen, et al., 2000).

CONCLUSION

Drop jumps are extremely important training tools for male and female triple jump athletes. They are used for improving the function of eccentric-concentric muscular functioning in the lower extremities. In addition, these jumps are a very reliable and objective measuring instrument in the diagnostics and planning of the training process. Modern diagnostics is based on some entirely new measuring technologies and an inter-disciplinary approach to the training process. Studies in the area of take-off strength of male jumpers, which have been carried out with integrated measuring systems, such as tensiometric force plates, infra-spectral CCD kinematic systems and electromyography methods can provide such relevant information, which is extremely important for the development of results in track and field jumping events. Drop jumps are, according to dynamic and kinematic structures and neuro-muscular mechanisms, very similar to triple jump. The current study has revealed that drop jumps from a height of 45 cm provide the best effects in the development of take-off strength in conditions of eccentric-concentric contractions.

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BIODINAMIČKA ANALIZA SKOKA IZ NASKOKA VRHUNSKIH SPORTISTKINJA

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Cilj ovog istraživanja bio je da pruži biodinamičku analizu kinematičkih i dinamičkih parametara na primeru dve vrste skoka iz naskoka (sa visine 25 cm i 45 cm). Uzorak ispitanika sastojao se od četiri vrhunske skakačice troskoka čiji su najbolji rezultati u rasponu od 13.33 do 15.03 metara. Kinematički i dinamički parametri su izračunati upotrebom tenziometrijskog aparata, čiji rad je sinhronizovan sa radom devet CCD Kamera. U skoku iz naskoka sa visine od 25 cm, ispitanici su postigli sledeće rezultate: visina skoka 43.37 ± 5.39 cm i jačina odraza 2770 ± 411 N. U poređenju sa tim, rezultati postignuti u skoku sa visine od 45 cm bili su: visina skoka 45.22 ± 4.65 cm i odraz od poda 2947 ± 366 N. Vertikalno ubrzanje pri odrazu kod skoka sa visine od 25 cm bilo je 2.77 ± 0.19 ms^{-1} a sa 45 cm 2.86 ± 0.15 ms^{-1}.

Ključne reči: *atletske discipline, biomehanika, skok sa naskoka, dijagnostika.*