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Kinematic, Dynamic and EMG Analysis of Drop Jumps in Female Elite Triple Jump Athletes

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A B S T R A C T

The purpose of the study was a biodynamic analysis of the kinematic, dynamic and EMG parameters of two types of drop jumps (heights of 25 cm and 45 cm). The sample of measured subjects included four female elite triple jump athletes, with their best results varying from 13.33 to 15.06 meters. The kinematic and dynamic parameters were calculated with the use of a bipedal tensiometric force plate, which was synchronized with nine CCD cameras. A 16-channel electromyography (BTS Pocket, Myolab) was used to analyze the EMG activation of the following muscles: m. erector spinae, m. gluteus, m. rectus femoris, m. vastus medialis, m. vastus lateralis, m. biceps femoris, m. soleus and m. gastrocnemius medialis. In the drop jump from a 25 cm height, the measured subjects achieved the following results: height of jump 43.37±5.39 cm and ground reaction force 2770±411 N. In comparison, results for the drop jump from a 45 cm height were: height of jump 45.22±4.65 cm and ground reaction force 2947±366 N. 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 it was 2.86±0.15 ms^{-1}. Observation of the EMG activation revealed the proximal to distal principle of muscle activation at work in both types of drop jumps. In the first phase of the concentric phase the most active muscles were m. gluteus maximus and m. rectus femoris. The greatest activity of m. gastrocnemius medialis and m. soleus was noticed in the last third of the take-off action. Significantly high EMG activation of m. vastus medialis and m. vastus lateralis was already shown in the flight phase prior to the feet making contact with the ground.

Key words: *triple jump, biomechanics, plyometric jump, biodynamic parameters*

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 the run-up and the optimal proportion of individual jump lengths[1–3]. Each of the partial jumps involves a specific motor task with particular characteristics and tasks which athletes must fulfil in order to successfully execute a triple jump. According to some previous studies[1,2,4–6], maintaining the optimal horizontal velocity in the hop, step and jump phases is the most important factor of a maximal length in triple jump. The critical point in triple jump is the transition from the hop to the step phase. Efficient transformation of the run-up speed into the hop phase is connected with a correct rhythm and visual and kinesthetic control[1,7,8]. The first jump (the hop) is the longest and represents 36–39% of the overall length in triple jump[2,6–8]. The efficient execution of the first jump is therefore a key element of the successful completion of the following two jumps and consequently of the entire triple jump. The proportions of the lengths of the three jumps depend on various motor strategies of individual athletes. In practice, there are three different techniques in triple jump: »Hop dominated«, »Hop jump« and the »Balanced technique«. With the first technique, the emphasis is on the length of the first jump (the hop), with the second the stress is on the length of the last jump (the jump), while with the last technique the lengths of all three jumps are balanced. The lengths and proportions are defined by the execution of the support and flight phases. The transition of horizontal velocity also has a correlation with an efficient technique for the take-off action. In individual take-off actions some extremely high values of ground reaction

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force have been noticed. Some autors[5] found that among male triple jump athletes the maximal vertical ground reaction phase in the »hop« phase reached 7,945 N, in the »step« phase 10,624 N and in the »jump« phase 9,056 N. From a neuro-muscular system point of view, these loads exceed 15 times the body weight of athletes. In addition to the magnitude of the ground reaction force, the contact time of individual take-off actions is important. Several studies[2,5,6,8] have revealed the values of contact time of the first take-off action (the hop) between 0.120 and 0.139 seconds, in the second take-off action (the step) between 0.150 and 0.157 seconds and in the third take-off action (the jump) between 0.177 and 0.185 seconds.

In keeping with the 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[9-12] show that drop jumps from various heights are the best indicator of special take-off strength. The experimental procedure in the present study employed drop jumps of 25 and 45 cm height which generate an 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[13,14]. In the eccentric phase a certain amount of elastic energy is stored in a muscular-tendon complex, which can be spent in the second phase. Some of the elastic energy accumulated in a muscle is only available for a definite time, depending on the life span of cross bridges in a muscle, which is between 15 and 120 milliseconds[13,15–18]. The efficiency of the stretch-shortening cycle (SSC) also depends on the time of switching from an eccentric to a concentric contraction: the longer the switch, the lower the efficiency of the contraction. Besides the magnitude and velocity of changes in muscle length and the time of switching from the eccentric to the concentric phase, the preactivation of muscles is also very important for the efficiency of the stretch-shortening cycle[14]. Preactivation is defined by the first contact of the foot with the ground and is mainly manifested in sprints, horizontal and vertical jumps. Preactivation prepares muscles for stretching and is manifested by a number of joined cross bridges and changes in the excitation of ά-motor neurons. Both factors influence the short-range stiffness: greater stiffness leads to less stretching of the tendons and ligaments and consequently to the better integration of chemical and elastic energy in the muscle[13,14,19,20]. This results in the higher production of muscular force.

The purpose of the present study was to find the most important kinematic, dynamic and EMG parameters of four female elite athletes in drop jumps from 25 and 45 cm heights. The tests varied in their starting height. It may be assumed that in a drop jump from a 45 cm height the force of muscle stretching will be larger in the eccentric phase, which will consequently lead to the integration of elastic and chemical energy in the concentric phase of the take-off. As a larger amount of accumulated elastic energy will then be carried over to the concentric phase of the take-off, and assuming that a 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. The aim of the study is to examine the kinematic, dynamic and EMG parameters and find an optimal height of drop jumps that will have the largest effect on the required special strength in female triple jump athletes.

Materials and Methods

Subjects

The sample of measured subjects included the four best female triple jump athletes in Slovenia (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 these athletes was 13.74±1.4 m, the best jumper had a result of 15.03 m, achieving 6th place at the 2008 Beijing Olympic Games). The measured subjects were informed of the aim, goals and organization of the experiment, which was carried out according to the Helsinki-Tokyo declaration.

Study Design

The procedure of the experiment was carried out in laboratory conditions (Biomechanical Laboratory, Polyclinic for Physical Medicine and Rehabilitation Peharec in Pula, Croatia). The measured subjects performed drop jumps from 25 and 45 cm heights in a random order (Fig-

Fig. 1. Execution of a 25 cm drop jump. M.Š. one of the world's best female triple jump athletes (PB: 15.03 m), 6th place in final at 2008 OG in Beijing.

ure 1). When performing the jumps, the hands were fixed at hip height. Each jump was repeated three times, with the best result being included in the study. A system of 9 CCD cameras type SMART-e 600 (BTS Bioengineering, Padua) with 20 Hz frequency and a resolution of 768 x 576 pixels was used to achieve a 3-D kinematic analysis of the vertical jumps. Analysis of the kinematic parameters was carried out using the BTS SMART Suite program. A dynamic model was 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 the space was performed with the Thort2 (BTS SMART-D) system. The validity of the model was tested with a walking sequence in the sagittal and frontal planes. On the basis of the kinematic model of analysis the following parameters of drop jumps from 25 and 45 cm heights were examined: take-off height, duration of take-off phase, duration of eccentric phase, duration of concentric phase, take-off velocity, take-off velocity in eccentric phase and angles in knee and ankle joints.

Dynamic parameters of the 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 1,000 Hz. The ground reaction force was measured unilaterally and bilaterally (Figure 2). The analysis included the following dynamic parameters: maximal ground reaction force with the left and right leg, total impulse of the ground reaction force, the impulse of force with the left and right leg. A method of inverse dynamics was used to calculate Power (P) in the hip, knee and ankle joints and to normalize it to the body weight (Wkg-1, Figure 3). The calculation was carried out according to the following formula: Power (P. t) = M (t) x ω (t)[21].

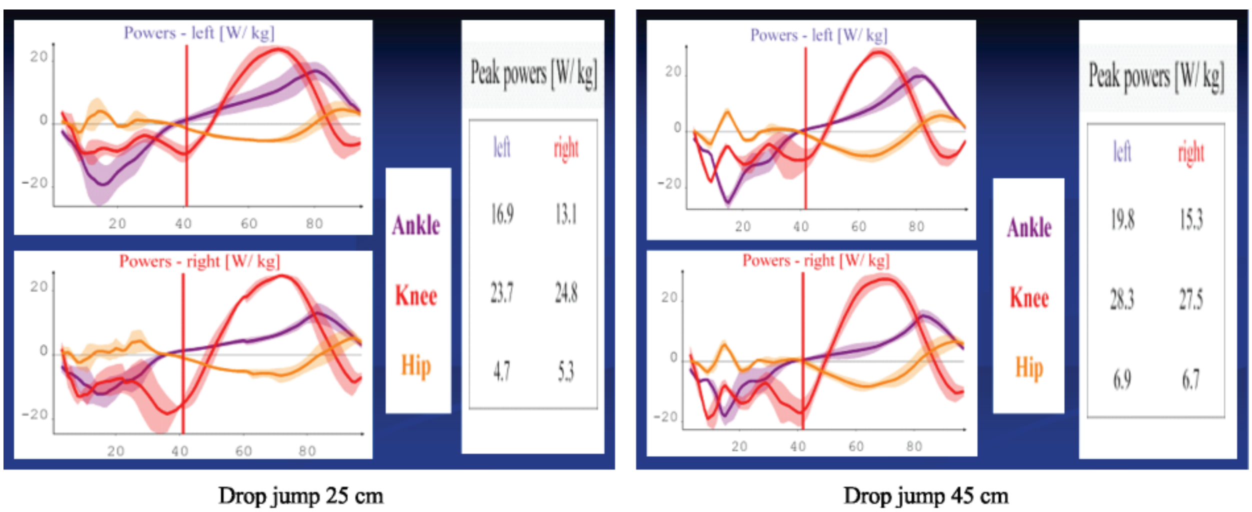

Fig. 2. Bilateral ground reaction force (L, R) in 25 and 45 cm drop jumps

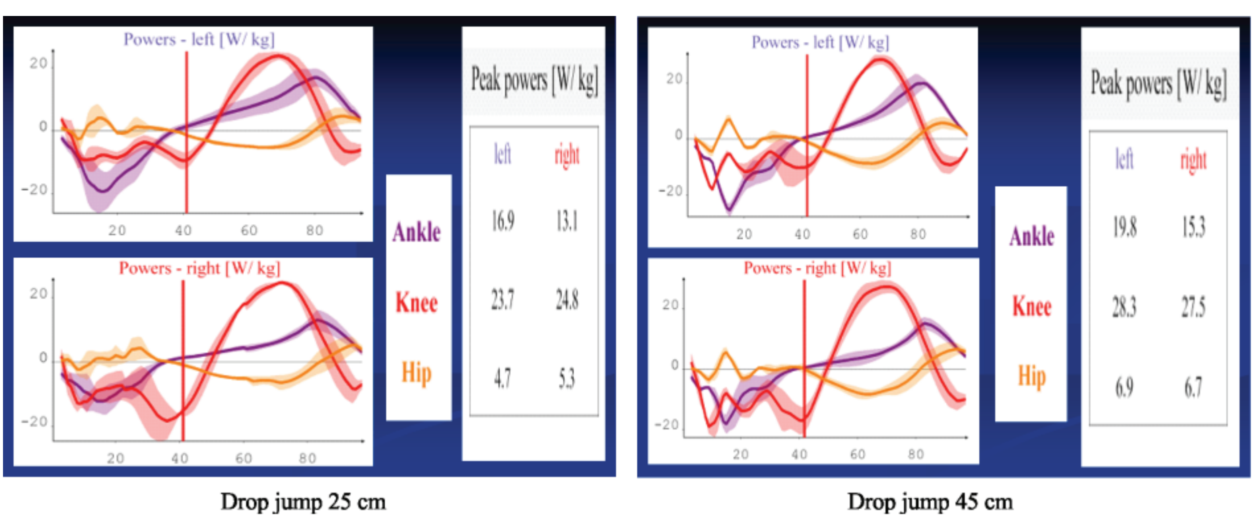

Fig. 3. Joint strength (P) in hips, knees and ankles, normalised to body mass (Wkg-1) according to Vaughan et al., 1999.

A 16-channel electromyography (BTS Pocket EMG, Myolab) was used to analyze the electrical activity of skeletal muscles (EMG). The electromyography consisted of two units: a mobile unit (HP Ipaq 4700), which captured all EMG signals and transmitted them to a stationary unit with the help of wireless (Wi-Fi) technology (Figure 4). An EMG activation of eight muscles of the left and eight muscles of the right leg was observed (m. erector spinae, m. gluteus maximus, m. rectus femoris, m. vastus medialis, m. vastus lateralis, m. biceps femoris, m. soleus, m. gastrocnemius medialis) and one of the muscles extending back (m. erector spinae). To detect the surface electrical activity of skeletal muscles, bipolar surface electrodes Ag-AgCl (Ambu Blue Sensor SE-00-S/50, Denmark) were used; they were placed on the corresponding location of the muscle motor unit after the skin had been thoroughly prepared. The procedure for placing the electrodes was carried out by a trained professional according to the Seniam method. The distance between the electrodes was 2 cm and the resistance between them was from 1 to 5 kΩ. During the experiment, captured signals were adequately filtered and smoothed. First, a high-pass filter Hamming at 30 Hz frequency was used to remove artefacts. The signal was then integrated with a RMS algorithm on a 20 millisecond time basis. The next smoothing was carried out with a low-permeated filter Hamming at 10 Hz frequency (Figure 5). Normalization of the EMG signal was carried out for comparing individual repetitions of jumps and for comparing the measured subjects. The method used the measured maximal intended isometric contraction and was carried out with the help of an isometric splint for chosen muscle groups.

Fig. 4. Procedure of the EMG measurements, calibration of the 16-channel electromyograph

Data analysis

Data analysis methods involved calculating descriptive statistical parameters: arithmetic mean (M) and standard deviation (SD). The results were statistically analyzed with the SPSS computer program.

Results

The results in Tables 1 and 2 reveal that the athletes on average achieved better results for the drop jump from a 45 cm height (45.22±4.65 cm). The difference between the 25 and 45 cm drop jumps was 1.47 cm. The best result (51 cm) was achieved by subject A, who also possessed the best triple jump result. The average value of the measured subjects' contact time was lower in the drop jump from a 45 cm height. The duration of the eccentric phase did not vary between the jumps; however, a difference in the concentric phase is apparent. Namely, in the drop jump from a 45 cm height, the duration of the concentric phase was more than 3 milliseconds shorter. The surface reaction force in the drop jump from a 45 cm height was recorded at 2,947±366 N, compared to 2,770±411 N in the drop jump from a 25 cm height. Separate results of the ground reaction force measured with the bipedal force platform revealed that the measured subjects developed greater force with the left (dominant) leg in drop jumps from both heights. The difference in the ground reaction force between the left and right leg amounted to 34 N in the drop jump from 25 cm and 21 N from the 45 cm height. The vertical velocity of the take-off in the drop jump from 25 cm was recorded at 2.77±0.19 ms^{-1} and 2.86 ±0.15 ms^{-1} in the 45 cm drop jump. The velocity of the measured subjects in the eccentric phase of the take-off in the 45 cm drop jump was 0.41 ms^{-1} larger than in the 25 cm drop jump. The amplitude of the knee flexion was identical in both drop jumps.

Discussion

Drop jumps are one of the most important methods in the training process of female and male triple jump athletes. In addition, they are an important diagnostic instrument for controlling specific take-off power. Triple jump is a typical track and field discipline where a competitive result is mostly generated by the horizontal velocity and take-off strength of an athlete. Execution of the three jumps (the hop, step and jump) is correlated with eccentric-concentric neuro-muscular modulation of force development. Drop jumps have a very similar modulation of force development. In drop jumps the degree of loading is defined by the height of the jump, the athlete's mass, the contact time and the height of the vertical jump. In these jumps the plantar flexors of the feet as well as the extensors of the knee and hip joints are under the greatest pressure. The landing must be executed so that the heels do not touch the ground. The contact of a heel with the ground causes the ground reaction force to increase by more than 100%. When the extensors of the ankle joints cannot guar-

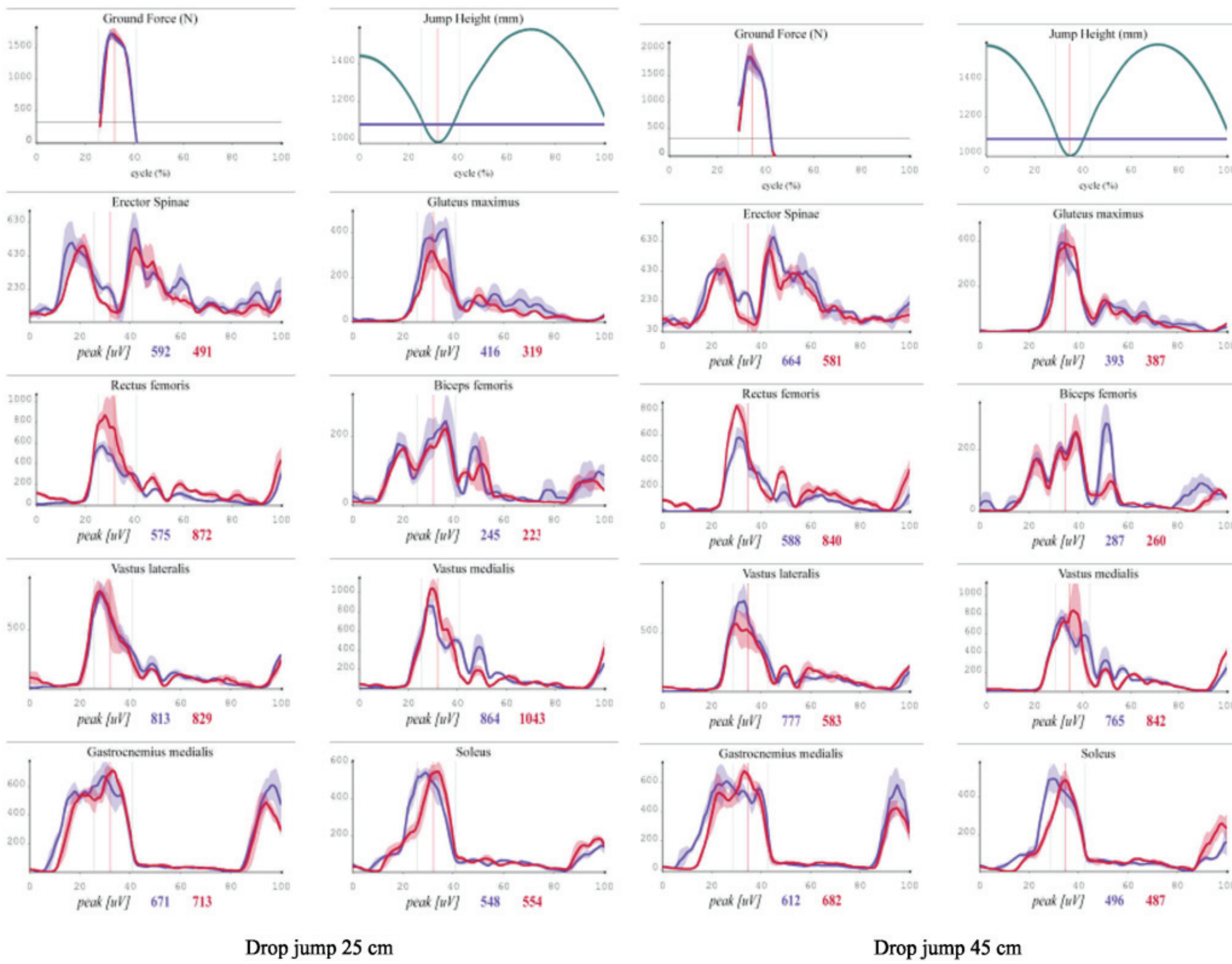

Fig. 5. EMG activation of muscles of lower extremities in the 25 and 45 cm drop jump.

antee deceleration in the eccentric phase, then the function is assumed by the knee and hip extensors. However, in this case the duration of the transition from the eccentric to the concentric phase is significantly increased, which holds negative consequences for the efficiency of the jump.

Besides the stretch-shortening cycle[14,20,] adequate preactivation is crucial to the efficiency of drop jumps. The preactivation phase begins 40–60 milliseconds prior to the feet making contact with the ground[22,23]. The function of muscle preactivation is to appropriately prepare to stretch the muscle. This is enabled by the co-activation of m. gastrocnemius and m. tibialis anterior[12]. Rigidness of m. gastrocnemius thus facilitates the storage of a larger amount of elastic energy in a tendon and the reduced lengthening of a muscle[20,24,25]. The purpose of drop jumps is to reduce the duration of amortization, which generates the optimal switch from an eccentric to a concentric contraction. If an eccentric contraction is not followed quickly enough by a concentric one, there is a loss of the elastic energy which has been stored in the cross bridges of muscles. In a phase of muscle and tendon elongation (pre-stretch), the main part of elastic energy is stored in serial elastic muscle elements – aponeurosis, tendons and cross bridges[18,26]. Some of the elastic energy is only available for 15–100 milliseconds[13,15,27]. The amount of elastic energy that is stored also depends on the force of the muscle stretch and the muscle-tendon complex stretch. Rigidity of both systems is therefore important. Triple jump athletes in particular develop more rigidity in muscles (m. gastrocnemius) than in the Achilles tendon[11]. It is a known fact that the muscle-tendon complex in conditions of a higher velocity stretch-shortening cycle can store a larger amount of kinetic energy in the form of elastic energy[12,19]. Generating elastic energy also means shorter contact times, which is a decisive factor for maintaining horizontal velocity in a triple jump. Where contact times with the ground are longer (more than 200 milliseconds), some of the absorbed elastic energy transforms into heat energy[12,20]. Studies have revealed[5,6] that among female elite triple jump athletes the contact times vary in the different jumps (hop, step, jump) from 120 to 185 milliseconds. Similar results were revealed in drop jumps on the sample of female athletes in the present study.

TABLE 1
KINEMATIC AND DYNAMIC PARAMETERS OF THE 25 CM DROP JUMP (DROP JUMP 25 CM)

Parameter	Unit	A	B	C	D	$\overline{X}$	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
DJ25ANKLEL	deg	20	10	23	23	19.50	6.65
DJ25ANKLER	deg	20	11	24	24	20.00	6.37
DJ25KNEEL	deg	54	42	62	62	54.75	9.21
DJ25KNEER	deg	50	26	70	70	51.50	18.85

DJ25H – height of jump, DJ25TIMECON – duration of concentric phase of take-off, DJ25TIMEECC – duration of eccentric phase of 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, DJ25ANKLER – angle of knee joint (right leg), DJ25ANKLEL – angle of knee joint (left leg), DJ25KNEER – angle of ankle joint (right leg), DJ25KNEEL – angle of ankle joint (left leg)

TABLE 2
KINEMATIC AND DYNAMIC PARAMETERS OF THE 45 CM DROP JUMP (DROP JUMP 45 CM)

Parameter	Unit	A	B	C	D	$\overline{X}$	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
DJ45ANKLEL	deg	18	10	24	24	19.00	6.63
DJ45ANKLER	deg	21	12	24	26	20.75	6.18
DJ45KNEEL	deg	54	44	58	60	54.00	7.11
DJ45KNEER	deg	50	32	64	60	51.50	14.27

DJ45H – height of jump, DJ45TIMECON – duration of concentric phase of take-off, DJ45TIMEECC – duration of eccentric phase of 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 take-off, DJ45DOWN – eccentric velocity, DJ45ANKLER – angle of knee joint (right leg), DJ45ANKLEL – angle of knee joint (left leg), DJ45KNEER – angle of ankle joint (right leg), DJ45KNEEL – angle of ankle joint (left leg)

According to the results of the present study, it may be concluded that in the 45 cm drop jump the sample of female triple jump athletes achieved a larger 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 a greater bilateral ground reaction force (2,947±27.88 N) at identical amplitudes in the knee and ankle joints. In the 45 cm drop jump, the athletes developed a 7.01% larger ground reaction force than in the 25 cm drop jump. Individual results showed the unilateral ground reaction force of the left (dominant) leg at 1,402±492 N and of the right leg at 1,368±358 N. The difference in the maximal ground reaction force between the dominant and non-dominant leg was 34 N, whereas in the 45 cm drop jump it was only 21 N. All but one of the measured subjects (subject C) developed a larger ground reaction force with the dominant leg for both types of drop jump.

Drop jumps from a 45 cm height require larger eccentric velocity in the amortization 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 an eccentric contraction to a concentric contraction whilst using the stretch reflex allows the efficient transfer of elastic energy from the first to the second phase of the take-off action. This was clearly manifested with the vertical velocity of the take-off in the concentric phase of a jump. In the 45 cm drop jumps the female jumpers achieved a vertical take-off velocity of 2.86±0.15 ms^{-1}, compared to 2.77±0.19 ms^{-1} in the 25 cm drop jumps. The best athlete, subject A, also showed the largest absolute take-off velocity of 3.09 ms^{-1}. Vertical take-off velocity is strongly correlated with the height of a jump. In the 45 cm drop jump the female athletes achieved on average 3.3% better results than in the 25 cm drop jump. The average value of the height of a jump in the 25 cm drop jump was 43.75±5.13 cm and in the 45 cm drop jump it was 45.22±4.65 cm. Subject A also achieved the best absolute height of a jump of 51 cm.

A basic precondition for the efficient execution of drop jumps is suitable preactivation of agonist and antagonist muscles, which provide increased rigidity of the ankle joint. Rigidity is a responsibility of the central motor program (joint stiffness regulation), which controls and synchronizes the functioning of the flexors and extensors of the feet prior to making contact with the ground[14,23,28,29]. This preactivation is revealed in the low amplitude of the plantar flexion of a foot on landing, which was measured at 52.7°±11.4°. Simultaneously, low amplitude was also revealed in the knee joint (19.9°± 1.8°).

With the help of inverse dynamics the strength of joints was observed in hips, knees and ankles in the 25 and 45 cm drop jumps. Strength was normalized according to the body mass of the female athletes (Wkg-1). In the 25 and 45 cm drop jumps the athletes showed the highest values in strength of the knee joint, then the ankle and hip joints (see Figure 3). The average value of the bilateral joint strength was 55.8 Wkg-1. Strong symmetry was revealed between the dominant and non-dominant legs. The unilateral joint strength of the knee was 28.3 Wkg-1 in the left leg and 27.5 Wkg-1 in the right leg for the 45 cm drop jump. The total joint strength of all three joints in the female athletes amounted in the 45 cm drop jump to 104.5 Wkg-1 and in the 25 cm drop jump to 88.5 Wkg-1. These values reveal the degree of loading of lower extremities, which are similar to competition conditions for female triple jump[1,5].

The method of surface electromyography was used with combined kinematic and dynamic parameters to monitor the EMG activation of selected muscles (m. gluteus maximus, m. rectus femoris, m. vastus medialis, m. vastus lateralis, m. tibialis anterior, m. biceps femoris, m. gastrocnemius medialis, m. soleus and m. erector spinae) whilst executing the drop jumps (see Figure 5). Comparative analysis of the pEMG amplitudes, which were normalized according to MVC (maximal conscious isometric contraction), revealed the proximal to distal principle of muscle group activation at work in the drop jumps. An exception to this principle is m. tibialis anterior, which was activated at the same time as m. erector spinae. These two muscles had already been activated in the phase of jumping off the bench. In the eccentric phase m. rectus femoris has an important activation function. In the concentric phase of take-off, this muscle is one of the first to be activated in addition to m. erector spinae and m. gluteus maximus, as the »prime mover« extending the hip joint. This muscle contributes the largest share to the starting vertical acceleration of the body's centre of gravity (BCG). The single joint muscles m. vastus lateralis and medialis as well as the two-joint muscle m. rectus femoris are the main extensors of the knee joint. They enter the take-off in the second third of the take-off action. M. gastrocnemius is in its function the main extensor of an ankle joint and a knee flexor. The energy produced in the extension of the knee joint is being transferred to the plantar flexion of the ankle[30]. The main function in the kinetic chain of vertical jumps is the transfer of energy between the segments (hip – knee – ankle). In the take-off action, the two-joint muscle m. rectus femoris transfers the energy from the torso and hip to the thigh and knee. The muscle m. gastrocnemius transfers the energy from the thigh and knee to the calf, ankle and foot[19,31] found that single-joint muscles provide initial mechanical energy in vertical jumps, whilst two-joint muscles monitor intramuscular coordination and the final vertical impulse. The greatest activity of m. gastrocnemius medialis and m. soleus was recorded in the last third of the take-off action. Particularly high EMG activation of m. vastus medialis and m. vastus lateralis can be observed already in the flight phase prior to a foot making contact with the ground. This muscle together with m. gastrocnemius medialis provides suitable coactivation of the knee joint. In relation to the dominant and non-dominant legs, a large symmetry can be noticed in the activation of muscles of lower extremities. The degree of EMG activation of the analyzed muscles is very similar for both types of drop jump. In the 45 cm drop jump slightly larger amplitudes of EMG activity were noticed in m. gastrocnemius and m. rectus femoris.

Conclusion

Drop jumps are extremely important training tools for male and female triple jump athletes. They are used to improve the function of eccentric-concentric muscular modulation in lower extremities. In addition, these jumps are a very reliable and objective measuring instrument for diagnostics and planning of the training process. At the present developmental level of track and field, the results already are and will in the future become progressively more a product of a carefully programmed and monitored training process. There will be ever less margin for coincidental factors of success. Modern diagnostics is based on some entirely new measuring technologies and an interdisciplinary approach to the training process. Studies in the area of the take-off strength of male jumpers 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 developing results in track and field jumping events. According to their dynamic and kinematic structures and neuro-muscular mechanisms, drop jumps are very similar to a triple jump. The present study revealed that drop jumps from a 45 cm height provide the best effects in terms of developing take-off strength in conditions of eccentric-concentric contractions. Nevertheless, since the sample of elite female triple jump athletes was relatively small the results must be observed with a certain amount of tolerance. Undoubtedly, the results of the current study importantly contribute to understanding the rules of plyometric strength training.

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KINEMATIČKA, DINAMIČKE I EMG ANALIZA KAP U SKOKOVIMA ŽENSKI ELITE TROSKOK SPORTAŠE

SAŽETAK

Svrha istraživanja bila je biodinamička analiza kinematičkih, dinamičkih i EMG parametara dvije vrste dubinskih skokova (visine 25 cm i 45 cm). U uzorak mjerenih ispitanika uključene su četiri elitne atletičarke troskoka, sa svojim najboljim rezultatima 13,33–15,06 metara. Kinematički i dinamički parametri su izračunati uz upotrebu sile dvopedalne tenziometrijske ploče, koja je sinkronizirana s devet CCD kamera. 16-kanalna elektromiografija (BTS džep, Myolab) je korištena za analizu EMG aktivaciju sljedećih mišića: erector spinae, gluteus, rectus femoris, vastus medialis, vastus lateralis, biceps femoris, soleus i gastrocnemius medialis. Kod dubinskih skokova s visine od 25 cm, izmjereni subjekti postigli su sljedeće rezultate: visina skoka 43.37±5.39 cm i sila reakcije tla 2770±411 N. Za usporedbu, rezultati za dubinski skok s visine 45 cm bili su: visina skoka 45,22±4,65 cm i sila reakcije tla 2947±366 N. Vertikalna brzina polijetanja kod dubinskog skoka od 25 cm bila je 2,77±0,19 ms-1, a kod dubinskog skoka od 45 cm 2,86±0,15 ms-1. Promatranje aktivacije EMG otkrila je proksimalni do distalni princip aktivacije mišića u radu u oba tipa dubinskih skokova. U prvoj fazi koncentrične faze najaktivniji mišići su gluteus maximus i rectus femoris. Najveća aktivnost gastrocnemius medialisa i soleusa primijećena je u posljednjoj trećini akcije polijetanja. Značajno visoka EMG aktivacija vastus medialisa i vastus lateralisa se pokazala već u fazi leta, prije nego noge stvore kontakt s tlom.