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BIODYNAMIC DIAGNOSTICS OF THE EXPLOSIVE POWER OF THE LOWER EXTREMITIES: A CASE STUDY

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SUMMARY

In many sports, vertical and drop jumps are an important exercise resource in an athlete's power training. This study aimed to establish the main dynamic and kinematic parameters that generate the efficiency of countermovement jump and drop jump, and establish the EMG activation of leg and back muscles. In the experimental procedures, one elite athlete triple jumpers took part. M. gastrocnemius medialis is one of the most important muscles in the production of mechanical energy in the kinetic chain. This is a two-joint muscle and can transfer energy between its segments. One-joint muscles generate the initial mechanical energy for vertical jumps, whereas two-joint muscles control the intramuscular coordination and the final vertical impulse. In a drop jump from 40 cm the ankle joint sustains the highest loading, followed by the knee joint and the hip joint. Based on this information the training process can be far more accurately programmed and controlled in terms of power.

Key words: biomechanics, dynamic, kinematic, EMG, countermovement jump, drop jump

INTRODUCTION

The movement structures that occur in specific sport situations are associated with different inputs of eccentric and concentric muscle contractions. The aim of training is often to modify the eccentric muscle contraction in view of its neurological characteristics. A good understanding of the role of eccentric muscle contraction in sport activities facilitates adaptation through the application of apposite training resources. The eccentric-concentric cycle consists of muscle stretching due to an external force and muscle shortening in the second phase, i.e. a stretch-shortening cycle (Zajac, 1993; Komi & Gollhofer, 1997; Mero et al., 2006) In the eccentric phase, a limited quantity of elastic energy accumulates in the muscle-tendon complex to be used in the second phase. This portion of elastic energy that is accumulated in the muscle is only available for a specific time. The available time depends on the life span of the cross-bridges and lasts from 15 to 120 milliseconds

(Cavagna et al., 1965; Enoka, 2003). As regards the production of force, it is essential that the muscle develops more force and consumes less chemical energy during an eccentric contraction compared to a concentric contraction (Asmussen, Bonde-Petersen, 1974; Cavagna, 1977; Buhrle et al., 1983; Bobbert et al., 1988; Komi & Gollhofer, 1997; Enoka, 2003, Marković et al., 2004). The efficiency of an eccentric-concentric contraction also depends on the time of the transition. The longer the time, the less efficient is the contraction. In addition to the extent and velocity of the change in the muscle's length and the duration of the transition, the efficiency of an eccentric-concentric contraction largely depends on pre-activation. Pre-activation prepares the muscles for stretching and is manifested in the number of attached cross-bridges and the change in the excitability of ά-motor nerves. Both factors affect the short-range stiffness of the muscle.

In functional and anatomical terms, the main role in a vertical jump is played by the two-joint thigh muscles which are also referred to as hamstrings or ischio-crural muscles by some authors (Brockett et al., 2004; Šarabon, 2005) This muscle group includes: m. semimembranosus, m. semitendinosus and m. biceps femoris. In specific sport situations these muscles are responsible for the primary extension of the hip joint in a closed kinetic chain and for flexion of the knee joint. The length of the two-joint thigh muscle is highly variable, depending largely on the position of the knee and hip joints (Šarabon, 2005). Its efficiency is best manifested in conditions of the high angular velocity of the joints of lower extremities. For that reason, the thigh muscles play an important role in fast explosive moves of acyclic and cyclic types.

In many sports, vertical and drop jumps are an important exercise resource in an athlete's power training. They enhance the eccentric-concentric muscle contraction of the lower extremities. At the same time, they are an indispensable measurement instrument in take-off power diagnostics. As regards their movement structure, vertical and drop jumps are similar to real motor situations in sports practice. Different test batteries are used to diagnose the explosive power of the lower extremities, either of a laboratory or a situational/field type. Bosco (1992) developed a classical protocol to monitor take-off power based on vertical jumps. Take-off power in concentric conditions of neuromuscular activity is measured by a squat vertical jump. Take-off power in conditions where the active muscles first extend (eccentric contraction) and then shorten (concentric contraction) is measured by means of a countermovement vertical jump and a drop jump.

When predicting results in track and field jump events, power (speed and strength) is undoubtedly one of the most important biomotor abilities. This is particularly valid in triple jump, which consists of run-up and three connected phases: hop, step and jump. Competition result depends on the optimal linking of individual phases; transition of horizontal velocity of an athlete is correlated with the technique of individual take-off actions. In triple jump, take-off actions are a clear example of development of the reaction force of surface in eccentric-concentric working conditions of muscular system. According to some studies (Luhtanen, Komi, 1980; Yu and Hay 1996), tests countermovement jump and drop jump have a high prediction value for triple jump results. Additionally, these two jumps are permanently used in the training of triple jump athletes. Motor structures of countermovement and drop jumps are from the biomechanical point of view very similar to the take-off action in triple jump. The present research study used the latest and most modern measuring technology in order to determine kinematical, dynamic and EMG characteristics in development of power in lower extremities. In this way, some correlations between causes and consequences of biodynamic factors in generation of muscular force in eccentric-concentric conditions of muscle work have been explained. Research has been carried out on a case study of one female triple jump athlete, although in the opinion of authors this does not reduce the importance of the study for sports science and applicative biomechanics. The highest standards of measuring procedures have been followed; therefore, results of the study can be used as valuable tools for planning, modelling and monitoring of training. Measured subject is one of the best female triple jump athletes in the world, placed 6th at the Beijing Olympic Games with a result of 15.03 metre.

Study aimed

1. Establish the main dynamic and kinematic parameters that generate the efficiency of vertical and drop jumps (countermovement jump and drop jump)
2. Establish the EMG activation of m. erector spinae. m. gluteus maximus, m. rectus femoris, m. biceps femoris, m. vastus lateralis, m. vastus medialis, m. tibialis anterior and m. gastrocnemius medialis in vertical and drop jumps (countermovement jump and drop jump)

METHODS

Sample

In the experimental procedures, one elite female athlete – triple jumper – took part (M. Š.: age 29 years, height 173.5 cm, body mass 59.0 kg). The vertical jump measurement protocol was carried out in the Biomechanical Laboratory of the Peharec Polyclinic for Physical Medicine and Rehabilitation in Pula, Croatia.

Data Collection

Each jump was performed three times. A system consisting of nine CCD SMART-e 600 video cameras (BTS Bioengineering, Padua) with a 50 Hz frequency and 768 × 576 pixel resolution was used for a 3-D kinematic analysis of vertical jumps. Kinematic parameters were processed by the BTS SMART Suite programme. A dynamic model featuring a system of 17 markers sensitive to infra-red light was defined (head, shoulders, forearm, upper arm, trunk, hips, thigh, shank, foot).

The dynamic parameters of vertical and drop jumps were established by using two independent force plates (Kistler, Type 9286A). The sampling frequency was 1000 Hz. The analysis was based on the following dynamic parameters: peak ground reaction force, force impulse and amount of work per 1 kg of body mass (concentric work J/kg). The ground reaction force was measured uni- and bilaterally. A 16-channel electromyograph (BTS Pocket EMG, Myolab) was used to analyse electromyographic activity (EMG). It consisted of two units: a mobile unit (HP Ipaq 4700) captured all EMG signals and transmitted them to the stationary unit using wireless technology (Wi-Fi). The EMG activation of seven muscles on the left and seven muscles on the right leg (m. gluteus maximus, m. rectus femoris, m. vastus medialis, m. vastus lateralis, m. tibialis, m. biceps femoris, m. gastrocnemius medialis) as well as one trunk extensor muscle (m. erector spinae) was monitored. Superficial electromyographic muscle activity was detected by means of bipolar surface electrodes Ag-AgCl (Ambu Blue Sensor SE – 00-S/50, Denmark), which were fastened to the specific location of a motor unit of each muscle, following thorough skin preparation (Figure 1). The electrodes were fastened by a qualified person. In the continuation of the experiment the recorded signals were filtered and smoothed. The statistical analysis of the results was processed with the SPSS statistical software.

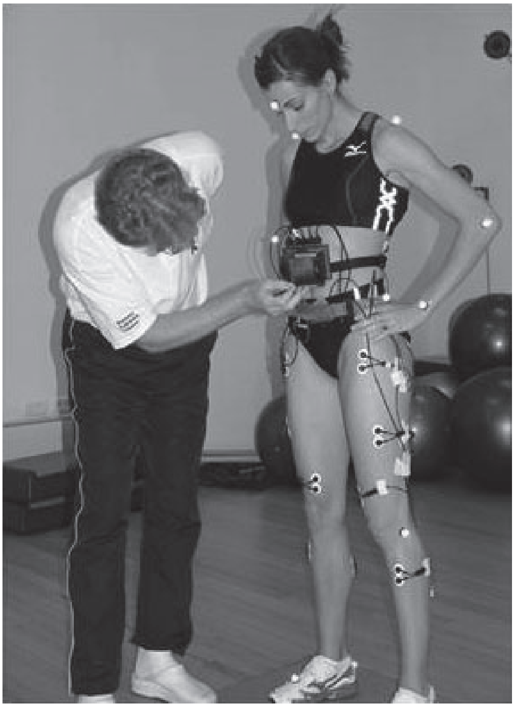

Figure 1. EMG measurement procedure of vertical jump and drop jump

RESULTS AND DISCUSSION

This motor task – countermovement jump consists of a rapid lowering of the body's centre of gravity, whereby the active leg muscles stretch (eccentric contraction). Then the movement is halted and the subject immediately takes off in a vertical direction (concentric contraction). The energy that accumulates in the muscles and the tendon during the stretching is transmitted to the concentric phase. Consequently, the velocity of movement in the second phase increases. The jump is performed with arms kept akimbo. The measurement protocol was based on the following parameters (Table 1, Figure 2).

Table 1. Dynamic and kinematic parameters of a countermovement jump and drop jump

Parameters	Unit	Countermovement Jump	Drop Jump 40 cm
Jump height	cm	48.8 ± 0.3	47.3 ± 0.8
Ground contact time	ms	364 ± 10	165 ± 5
Eccentric time	ms	123 ± 9	73 ± 2
Concentric time	ms	241 ± 6	92 ± 2
Concentric work	J/kg	6.4 ± 0.3	5.1 ± 0.2
Jump efficiency	cm/J	7.6 ± 0.4	9.3 ± 0.3
Peak power	W/kg	50.1 ± 0.9	92.4 ± 6.7
Flight time	ms	590 ± 21	580 ± 33
Take-off velocity	m/s	2.47 ± 0.3	2.78 ± 0.1
Peak force	N	904 ± 15	3654 ± 108
Eccentric impulse	Ns	34 ± 1	161 ± 4
Concentric impulse	Ns	178 ± 2	164 ± 1
Hip flexion	deg	77 ± 1	26 ± 2
Knee flexion	deg	89 ± 3	56 ± 2
Ankle flexion	deg	32 ± 1	13 ± 1

Figure 2. Measurement protocol for kinematic, dynamic and EMG parameters of countermovement jump

The take-off time ranges from 364 milliseconds. According to the principle of elastic energy transfer, the eccentric phase is shorter than the concentric one. Subject, whose jump height was 48.8 cm, had an eccentric/concentric phase ratio of 33.8% : 66.2%. It can be concluded that the efficiency of the two-phase muscular activity depends on an appropriate ratio between the eccentric and concentric muscle contraction. The elastic energy generated in the first phase thus accumulates in the muscle-tendon complex (tendon, aponeurosis, cross-bridges, perimysium, epimysium and sarcolemmas (Bobbert et al., 1987; Bobbert and van Ingen Schenau, 1988; Gollhofer, Kyrolainen, 1991) and merges with the chemical energy of the muscle in the concentric phase. The consequence is a larger muscle force, resulting in a higher jump. The vertical velocity of the body's centre of gravity in a two-phase muscle contraction is 9.5% higher than in a single-phase concentric muscle contraction. The transition from eccentric to concentric contraction takes place when the knee angle measures 89°. The ground reaction force ranges 904 N.

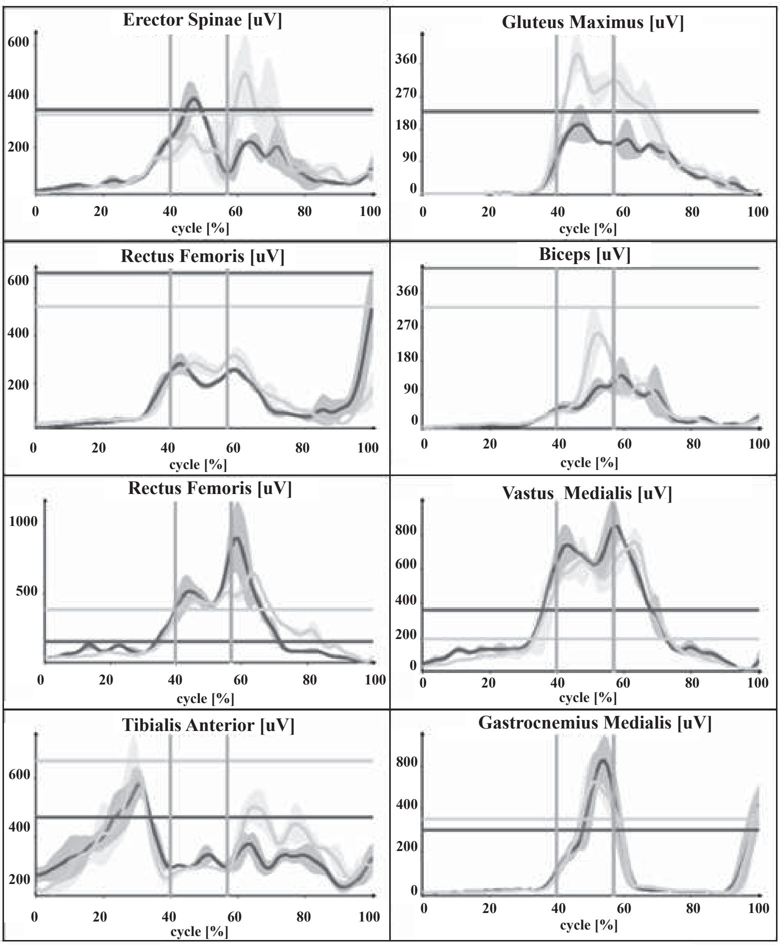

Figure 3. EMG activation of muscles in countermovement jump

The results of study subject showed that, in the eccentric and concentric phases, the EMG activation of the lower extremities' musculature in a countermovement jump was different (Figure 3). In the eccentric phase, a high level of activation was detected in the muscles m. erector spinae and m. gluteus maximus, whereas in the concentric phase the respective muscles were m. biceps femoris, m. vastus medialis and lateralis and m. gastrocnemius medialis. The bulk of mechanical energy at the end of the take-off is generated by m. vastus medialis and lateralis and m. gastrocnemius medialis. Part of the mechanical energy is transmitted from the ankle to the knee joint through m. gastrocnemius. From this joint, mechanical energy is then transmitted to the hip joint through m. rectus femoris. Rectus femoris is characterised by a high level of activation in both eccentric and concentric phases of the take-off action.

Figure 4. Measurement protocol for kinematic, dynamic and EMG parameters of drop Jump – 40 cm

A drop jump (Table 1, Figure 4) consists of the following phases: leaving the bench set at a specific height, flight, preparation for landing, ground contact, braking, eccentric-concentric contraction and vertical acceleration. Not only is the height of the bench important, but so too is the peak height of the body's centre of gravity during the flight phase. The pre-activation phase starts 100 milliseconds before the ground contact. The function of the muscle pre-activation is to prepare the muscle for stretching. This pre-activation is secured by the concurrent activation of m. gastrocnemius and m. tibialis anterior. The short-range stiffness of m. gastrocnemius thus facilitates the accumulation of a higher quantity of elastic energy in the tendon and a smaller extension of the muscle. The purpose of drop jumps is to shorten the time of shock absorption which generates an optimum transition from the eccentric to the concentric contraction.

Contact time is one of the crucial parameters of drop jumps as it defines the efficiency of the transition from the eccentric to the concentric contraction. The contact time of the study subject who performed a drop jump from a height of 40 cm ranged from 165 milliseconds. The ratio between the time of the eccentric and concentric phases of subject was 44.2% : 55.8%. Some authors (Luhtanen, Komi, 1980; Gollhofer & Kyrolainen, 1991; Schmidtbleicher, 1992) have shown that the pre-activation of plantar flexors is the most important mechanism in shortening the contact time in eccentric-concentric motor tasks.

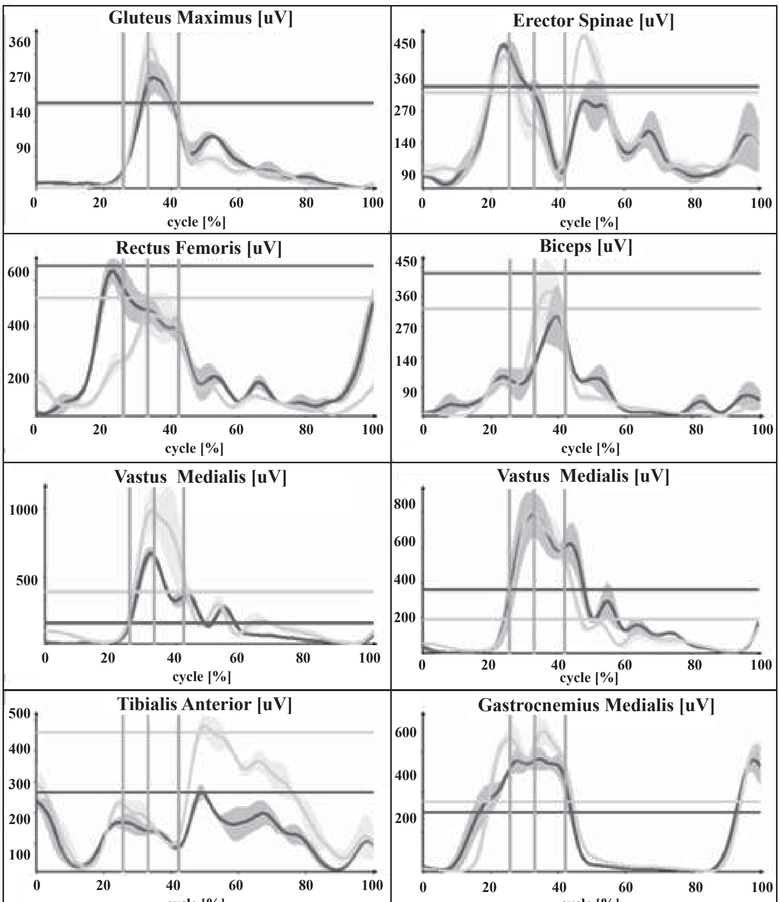

Figure 5. EMG activation of muscles in drop jump – 40 cm. (Darker line represent left leg muscles, brighter line represents right leg muscles. Shaded area around lines represents standard deviation of repetitive tasks. Horizontal lines represent maximal voluntary contraction that has been taken separately and follows the same brightness/darkness rules in respect to muscle activity envelope. Vertical line divide cycle with following rules: for countermovement jump, cycle is build from 'eccentric-concentric-flight' phase, for drop jump, cycle is build from 'preflight (dropdown)-eccentric-concentric-flight' phase

Basically, the central motor programme improves and – through control of musculature activation – increases the short-range stiffness of the muscle-tendon complex of the lower extremities upon contact with the ground. This programme is responsible for synchronisation of the ankle joint flexors and extensors. The optimum pre-activation of agonists and antagonists prior to contacting the ground reduces the amplitudes of movement and shortens the eccentric phase. Consequently, a larger muscle force is generated, along with a lower consumption of metabolic muscle energy. The shortening of the ground contact time in a drop jump is mainly the result of the pre-activation of m. gastrocnemius, m. soleus and m. tibialis anterior. Short-range muscle stiffness is additionally manifested in the ankle joint since the amplitude of the movement of subject was only 13°. The peak ground reaction force, measured by two force plates (Kistler, Type 9286A), was 3654 ± 108 N (drop jump from 40 cm). The peak ground reaction force and the peak force impulse were recorded in the eccentric phase.

The electromyographic method discloses important information on movement strategies in drop jumps (Figure 5). During the pre-activation and eccentric phases, it is possible to establish the peak activation of m. erector spinae, m. rectus femoris, m. tibialis anterior and m. gastrocnemius medialis. In the efficient pre-activation of muscles during their preparation for stretching, the concurrent activation of m. gastrocnemius and m. tibialis anterior plays a particularly important role. The former muscle is an agonist and the latter an antagonist . At the moment of contacting the ground, the highest EMG activation was recorded in m. rectus femoris, m. gastrocnemius medialis and m. tibialis anterior. The conclusion of the take-off action (concentric phase) depends on the EMG activation of m. gluteus maximus, m. vastus lateralis and medialis and m. gastrocnemius. The concentric phase lasts for 92 ± 2 milliseconds and the impulse measures 164 ± 1 Ns.

CONCLUSION

The biomechanical diagnostics of the explosive power of lower extremities is an extremely important element of monitoring modern athletes' training processes. The results of measuring different types of vertical and drop jumps provide us with fundamental information on the status and functioning of the neuromuscular system. Based on this information the training process can be far more accurately programmed and controlled in terms of power. Certain state-of-the-art technologies and measurement procedures for diagnosing explosive power have been presented, primarily as regards monitoring the dynamic and kinematic parameters of vertical and drop jumps. The tests are implemented in laboratory conditions, whereas the next step is to enable the monitoring of an athlete's neuromuscular system in field conditions, i.e. in a real environment.

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BIODYNAMICKÁ DIAGNOSTIKA EXPLOZIVNÍ SÍLY DOLNÍCH KONČETIN: PŘÍPADOVÁ STUDIE

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SOUHRN

V mnohých sportech jsou vertikální výskoky a seskoky důležitým zdrojem silového tréninku sportovců. Studie se zaměřila na určení hlavních dynamických a kinematických parametrů, které generují účinnost opačných pohybů – výskoků a seskoků a stanovení aktivace EMG nohou a zádových svalů. Experimentálnímu sledování byla podrobena elitní sportovkyně, trojskokanka. M. gastrocnemius medialis je jedním z nejdůležitějších svalů pokud jde o produkci mechanické energie v kinetickém řetězci. Jedná se o dvou-kloubový sval a může přenášet energii mezi jejími segmenty. jedno-kloubové svaly generují počáteční mechanickou energii při vertikálních skocích, zatímco dvou-kloubové svaly řídí mezisvalovou koordinaci a závěrečný vertikální impuls. Při seskoku z výšky 40 cm nejvyšší zatížení je udržováno v hlezenním kloubu, následuje kolenní a kyčelní kloub. Na základě těchto informací může být tréninkový proces daleko přesněji programován a z hlediska rozvoje síly řízen.

Klíčová slova: biomechanika, dynamické a kinematické parametry pohybu, EMG, výskok, seskok

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