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VARIABILITY OF BIOMECHANICAL PARAMETERS IN THE TRIPLE JUMP TECHNIQUE – A CASE STUDY

Milan Čoh[1] and **Otmar Kugovnik**[1]

[1]Faculty of Sport, University of Ljubljana, Slovenia

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SUMMARY

The purpose of the study was to examine consistency and variability of kinematical parameters in the triple jump technique. An analysis has been carried out on the basis of two attempts of a female athlete who is one of the best triple jumpers in the world. The latest biomechanical technology and the methodology of measurements in the triple jump have been used. The Opto-track technology and 3-D kinematical technology were used in order to analyse parameters of the model technique in the triple jump. The study revealed that optimal result in the triple jump can be achieved with different programme motor strategies. It has been revealed that the motor pattern is generated by consistent and variable parameters. The most consistent parameters of motor pattern were: partial distances of individual phases, duration of support phases in take-off actions, take-off angles and vertical amplitude of BCM. Variability of motor pattern has been revealed mostly in the following kinematical parameters: speed in the last 5 metres of run-up, distance and proportion of the last two run-up strides, horizontal velocity of BCM in take-off actions.

Key Words: triple jump, kinematic, biomechanical parameters, technique.

INTRODUCTION

From the biomechanical aspect, triple jump is one of the most complex track and field disciplines and consists of the run-up phase and three consecutive flight phases. The result is defined mainly with the speed of run-up and the optimal proportion between the distances of three flight phases (Hay, 1992; Hay & Miller, 1985; Grahman-Smith & Lees, 1994; Miladinov & Bonov, 2004). Each of the structural units represents a specific motor task with certain characteristics and tasks, which an athlete has to complete in order to execute a successful triple jump. According to some of previous studies (Conrad & Ritzdorf, 1990; Grahman-Smith & Lees, 1994; Hay, 1999; Jurgens, 1998, Panoutsakopoulos & Kollias, 2008), preservation of optimal horizontal velocity in the hop, step and jump phases is a crucial factor for achieving maximal distance in the triple jump. A critical moment in the triple jump is a transition from hop into step phase. From the aspect of motor pattern structure, triple jump can be regarded as a connection of cyclic and acyclic movements. Efficient transformation of run-up speed into take-off for hop phase is correlated with the correct rhythm and visual as well as kinaesthetic control (Hay, 1999; Kyrolainen, Komi, Virmavirta, & Isolehto, 2007; Yu & Hay, 1996). The first phase (hop) is the longest and represents 36 – 39% of overall distance of three phases (Grahman-Smith & Lees, 1994; Kyrolainen et al., 2007; Panoutsakopoulos & Kollias, 2008). Therefore, an efficient execution of hop phase is a key element for execution of the next two phases (step and jump) and thus the entire triple jump. The proportion of distances of three phases depends on various motor strategies for both genders of triple jumpers. Three techniques of triple jump have been identified: “Hop Dominated”, “Hop Jump” and “Balanced” technique (Panoutsakopoulos & Kollias, 2008). In the first (hop dominated) technique an emphasis is on the distance of first phase (hop), in the second technique an emphasis is on the distance of last phase, whereas in the third technique a balance between the distances of all three phases is emphasised. Distances and proportions of different phases are defined with the execution of support and flight phases. Transition of horizontal velocity is correlated mostly with the efficient technique of take-off action. The optimal proportion between horizontal and vertical component of body centre of mass (BCM) velocity in support phase is very important. An athlete should maintain as large horizontal velocity as possible whilst ensuring adequate vertical velocity for an efficient triple jump. The increase of horizontal velocity component results in reduced vertical velocity component and vice versa.

It seems that the final result in the triple jump is a product of various types of technique and other factors as well as their correlations. The Bernstein theory (Latash, 1994) defines sports technique as a managed process with compensational and self-regulative characteristics. An athlete cannot control all the motor process phases, although the motor pattern is standardised and automated (Schmidth & Lee, 1999). In order for the motor pattern to be correct and rational, its individual elements have to be coordinated in such way that some follow the principle of parallel execution and others the principle of consequent execution. Optimal coordination of the motor pattern is possible only if it is programmed. An athlete possesses programmes and sub-programmes in a primary motor centre of central neural system; they are either permanent either acquired according to the external and internal circumstances (Enoka, 1998). The movement cannot be executed correctly without the existence of a suitable programme.

Normally, the technique in elite sportsmen is never absolute. Every athlete constantly keeps perfecting his / her technique and adapting it to the numerous external and internal factors. Basic elements of technique are stable; nevertheless, some subtle technical elements change. The complete stabilisation of technique is not possible due to various endogenous factors (mental status, degree of sports form, pressure, competitive stress) and exogenous factors (micro-climatic conditions: wind, outside temperature, height above sea level; sports infrastructure: different structure and elasticity of the surface).

According to the Bernstein's theory (Latash, 1994) two programme strategies for solving the motor pattern exist in the conditions of high degree of movement stabilisation. According to the first strategy, it is possible to realise the motor pattern by keeping the technical parameters constant. The second strategy of realisation of motor pattern is based on the consistency of some and variability of other technical parameters. The aim of the present study was to examine consistency and variability of parameters in the triple jump technique of an elite female track and field athlete of highest international quality. Analysis included two best triple jump attempts (attempt A, attempt B). The official distance of the attempt A was 13.68 m with the effective distance 13.85 (toe-to-board distance = 0.17 m). The official distance of the second attempt was 13.63 m and the effective distance 13.66m (toe-to-board distance = 0.03 m). The difference in the effective distance between the two attempts was 0.19 m.

METHODS

The measured subject is one of the best female triple jumpers in the world, M. Š. (age 28, height 172 cm, weight 66.5 kg, personal triple jump record 15.03m, 6th place at the 2008 Olympic Games) - Figure 1. Measured subject had six attempts and the two longest jumps were included in the study. Measurements were carried out in the preparation phase prior to the 2008 Olympic Games in Beijing. *Opto-Track* technology by the Italian manufacturer Microgate was used to measure the distances of different phases, support and flight times in the run-up phase as well as in hop, step and jump phases. The basic components of the measuring system represent interlinked rods (100 cm x 4 cm x 3 cm), with built-in optical sensors and the computer programme for data recording and analysis. Each of the rods contains 32 sensors – photo cells, which are positioned every 4 cm and placed 0.2 cm above the surface. The total length of interlinked rods was 20 metres. The rods of the measuring system were placed on each side of the run-up track (width = 1.22 m). A system of infrared photo cells (*Brower* – Timing System) has been used in order to measure the run-up speed (11-6 m, 6-1 m). Kinematical analysis has been carried out with the use of recordings made via four synchronised video cameras (*Sony DVCAM DSR-300 PK*) with the frequency of 50 Hz and definition of 720 x 576 pixels, which were placed on a 90° angle to the optical axis. The first two cameras have covered the area of last two steps in the run-up and hop phase, the remaining two cameras have recorded step and jump phases of the triple jump. In order to achieve better precision and for the purpose of biomechanical analysis of the take-off action in hop and step phases, two high-speed digital cameras *Mikrotron Motion Blitz Cube ECO-1* and *Digitional motion analysis recorder* were used. The cameras could record 6 seconds of movement with the frequency of 100 frames per second and definition of 640 x 512 pixels; however, a frequency of 500 frames per second has been chosen for the present study. The analysed area of the last two run-up steps and three triple jump phases (hop, step and jump) have been calibrated with a referential measuring frame with dimensions 1 m x

FIGURE 1
Marija Šestak is one of the best female triple jump athletes in the world, with a distance of 15.03 metres she has won 6th place at the 2008 Olympic Games in Beijing

1 m x 2 m, whilst considering eight referential corners (Figure 2). The length of analysed movement has been defined with "x" axis, height with "y" axis and depth with "z" axis. For calculation of kinematical parameters of technique, a 3-D software equipment APAS (Ariel Dynamics Inc., San Diego, Ca) was used (Figure 3). Digitalisation of 15-segment model of the athlete's body has been performed; the model has been defined with 18 referential points (Dempster, cited in Miller & Nelson, 1973). The coordinates of body points were smoothed with a digital Buterworth level 7 filter. SPSS software package has been used for statistical data analysis.

RESULTS

Optimal speed, good visual control and well-structured run-up in the last three strides are basic requirements for a good triple jump result. According to the Table 1, it can be noticed that the measured subject developed identical speed (6.94 ms^{-1}) in the 11 – 6 metre zone prior to the take-off board in both of the analysed attempts. The speed differentiated significantly in the 6 – 1 metre zone. Namely, in the attempt B the measured subject achieved higher speed than in the attempt A by 0.57 ms^{-1}. The structure of the run-up in the last two strides (1L and 2L) also differentiated significantly in both stride length and speed. In both attempts the second to last stride was slightly longer than the last stride. A tendency of a longer last stride has been noticed also in some other elite female triple jumpers. The length of the last stride is correlated with the efficient transformation of horizontal into vertical velocity, which ensures the required height of the body centre of mass (BCM) trajectory in the first (HOP) phase.

DISCUSSION

According to the total and relative distances of individual phases, the measured subject is a typical representative of a »Hop Dominated« technique with particularly emphasised last (*jump*) phase. The proportion of partial distances of individual phases (*hop-step-jump*) did not differentiate significantly between the attempts. In the attempt A the distance of the first phase (*hop*) was 4.73 m (34.6%), second phase (*step*) 4.01 m (29.3%) and third phase (*jump*) 4.94 m (36.1 %). Apparently, the motor strategy of a measured subject in this phase is very stable. Kyrolainen et al. (2009) have found that the proportion between different partial phases of female athletes at the 2005 World Championships in Helsinki amounted to 36.2% : 29.4% : 34.5%. »Hop Dominated« technique is most often in both male and female triple jumpers. The characteristic of representatives of »Hop Dominated« technique is large horizontal velocity, which is developed in the run-up and the first take-off action. The characteristic of measured subject M. Š. is to have larger potential in elastic strength than in speed, the former being utilised mostly in the second and third phases of the triple jump. Partial distances of phases and their proportions are influenced by the morphological characteristics, bio-motor abilities, coordination, visual perception and the ability to control a movement in the athlete (Latash, 1994; McGinnis, 1999; Schmidth & Lee, 1999; Winter, 1990). Therefore, optimal proportions between partial phase distances extremely depend on individuals (Hay, 1992).

In the measured subject, partial phase distances were in strong correlation with the duration of support and flight phases. In the attempt A, the duration of the support part in the *hop* phase was 0.11 second, in the *step* phase 0.15 second and in the *jump* phase 0.16 second. Support times increased with the reduction of horizontal velocity of BCM (Figure 3). The athlete M. Š. slightly deviates from the model of support times of other elite female triple jumpers (Kyrolainen et al., 2009) in the last take-off and flight phase of the *jump* phase. The last phase (*jump*) is in its kinematical structure more similar to the long jump. Partial contribution of the *jump* phase to the final result amounted to high 36.1 %. In the last phase a high value of take-off angle (27.70) has also been noticed. Kinematical parameters of the attempt B were almost identical in the duration of support and flight phases as well as in take-off angles of the take-off action (*hop, step, and jump*). The value of take-off angle in the last (*jump*) phase differentiated significantly from some of the previous studies (Kyrolainen et al., 2009; Mendoza & Nixdorf, 2010; Panoutsakopoulos &

FIGURE 2

The 3 D kinematic analysis of triple jump

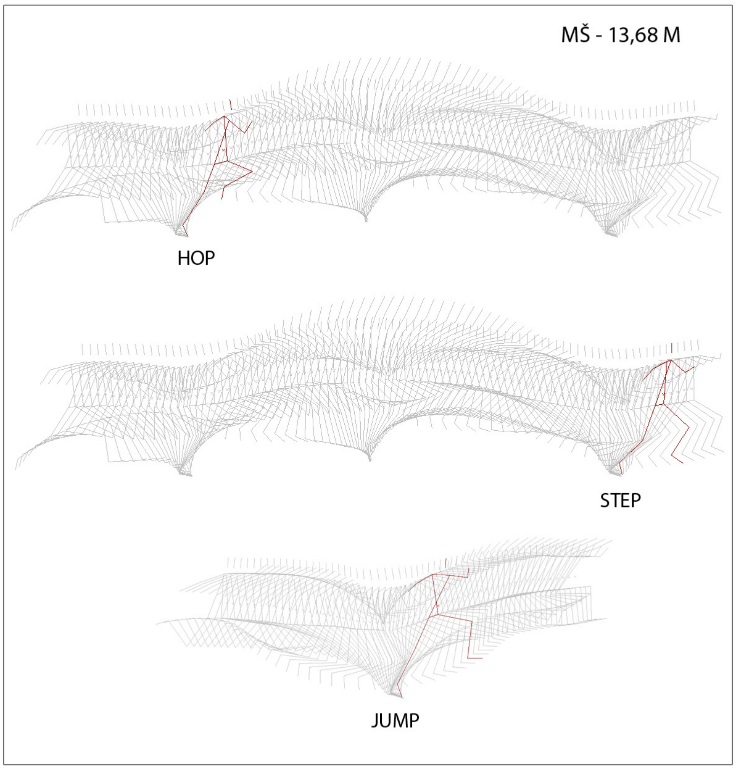


TABLE 1

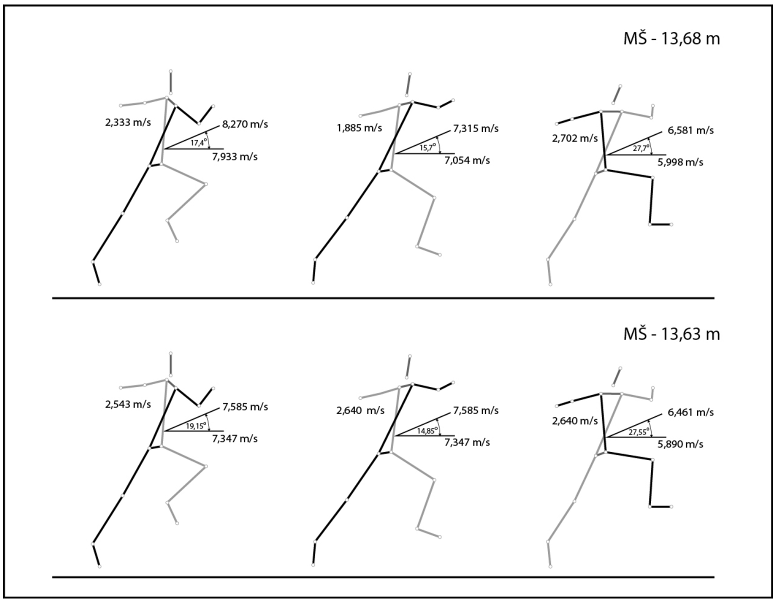
Variability of kinematic parameters in the triple jump technique

Parameters	Phase	Attempt A	Attempt B
Result (m)		13.68	13.63
Effective distance (m)		13.85	13.66
Run –Up Velocity (ms^{-1})	11 - 6	6.94	6.94
	6 - 1	8.20	8.77
Run – Up Stride length (m)	2L	2.20	2.17
	1L	2.30	2.18
Run – Up Velocity (ms^{-1})	2L	8.25	8.40
	1L	8.35	8.41
Stride length (m)	Hop	4.73	4.73
	Step	4.01	3.92
	Jump	4.94	4.98
Relative distance (%)	Hop	34.60	34.70
	Step	29.30	28.80
	Jump	36.10	36.50
Horizontal velocity (ms-1)	Hop	7.88	7.93
	Step	7.35	7.06
	Jump	5.89	6.00
Loss of horizontal velocity (ms^{-1})	Hop	-0.47	-0.48
	Step	-0.53	-0.87
	Jump	-1.46	-1.06
Vertical velocity (ms^{-1})	Hop	2.54	2.33
	Step	1.86	1.88
	Jump	2.64	2.70
Duration of the support phase (s)	Hop	0.11	0.12
	Step	0.15	0.15
	Jump	0.16	0.17
Duration of the flight phase (s)	Hop	0.48	0.48
	Step	0.39	0.39
	Jump	0.65	0.66
Angle off take-off (°)	Hop	19.20	17.40
	Step	14.90	15.70
	Jump	27.50	27.70
Maximal height of the C.C (m)	Hop	1.06	1.07
	Step	1.06	1.08
	Jump	1.15	1.15
Minimal height of the C.C (m)	Hop	0.90	0.89
	Step	0.90	0.91
	Jump	0.91	0.90

Kollias, 2008). Large take-off angle also resulted in the high flight trajectory of the BCM and was manifested in duration of the last flight phase in the *jump* (0.65 – 0.66 s).

Undoubtedly, the horizontal velocity in individual take-off phases is a crucial generator of competition success in this track and field discipline. The smaller decrease of horizontal velocity, the better is final result. The measured subject has achieved the highest horizontal velocity in her last stride (L1) in both the attempt A (8.35 ms^{-1}) and the attempt B (8.41 ms^{-1}). Decrease of horizontal velocity at the end of take-off action in *hop* amounted to -0.47 ms^{-1} or 5.6 % in attempt A and – 0.48 ms^{-1} or 5.7 % in attempt B. In the

FIGURE 3
Kinematics of technique in the HOP-STEP-JUMP phases



take-off action of the *step* phase the horizontal velocity decreased by 7.3 % in attempt A, whereas in attempt B it decreased by 10.9%. In the *jump* phase the decrease of horizontal velocity in comparison to the previous take-off action amounted to 19.8 % in attempt A and 15.0 % in attempt B. The difference in horizontal velocity of the BCM was noticeable only in the take-off action of *step* phase, which has been manifested in slightly shorter partial distance of this phase in attempt B

The reduction of horizontal velocity is a result of ensuring the optimal vector of vertical velocity. Vertical velocity is the highest in the first (*hop*) and last (*jump*) phases of both analysed attempts. The lowest vertical velocity has been recorded in the *step* phase (A = 1.86 ms^{-1}, B = 1.88 ms^{-1}). The basic strategy of the measured subject is to preserve as high horizontal velocity as possible whilst ensuring the optimal vertical velocity (Figure 5). The magnitude of vertical velocity is correlated with the take-off angle, which was also the highest in the first and third phases of

FIGURE 4
Horizontal velocity of BCM and the duration of support phases – M. Š: 13.68 m

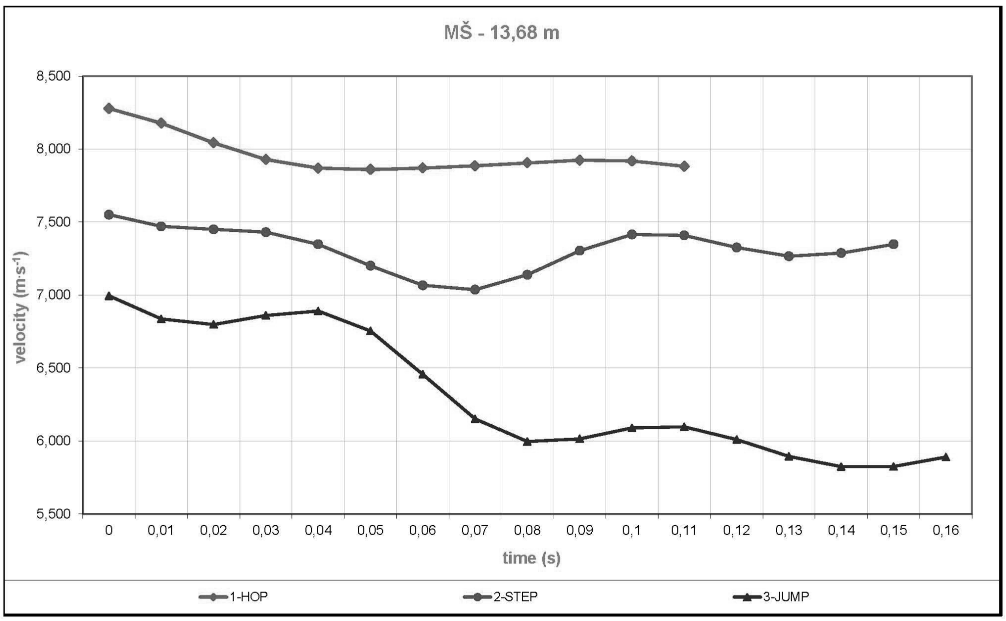
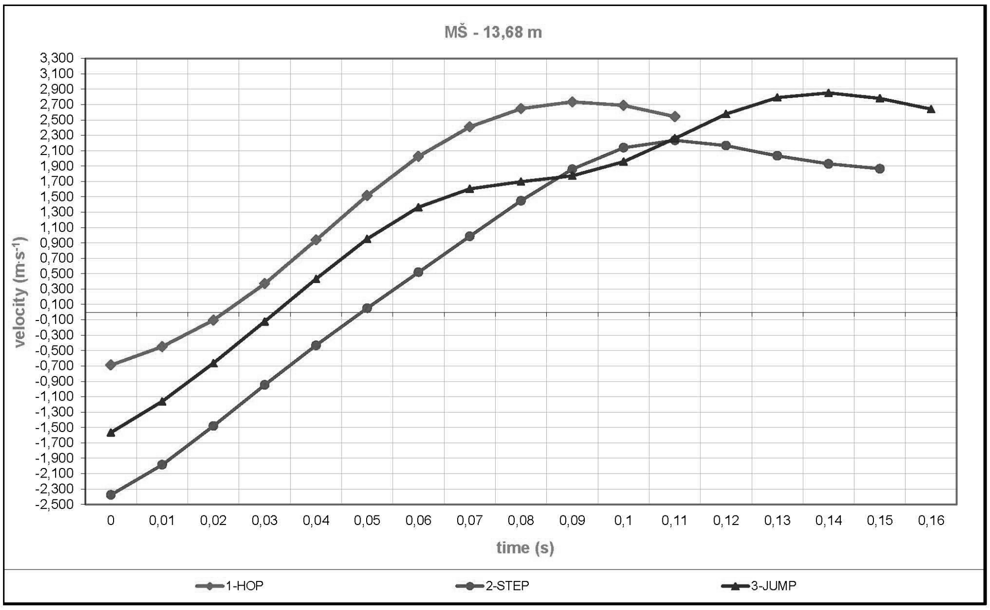


FIGURE 5

Vertical velocity of BCM and the duration of support phases- MŠ: 13.68 m



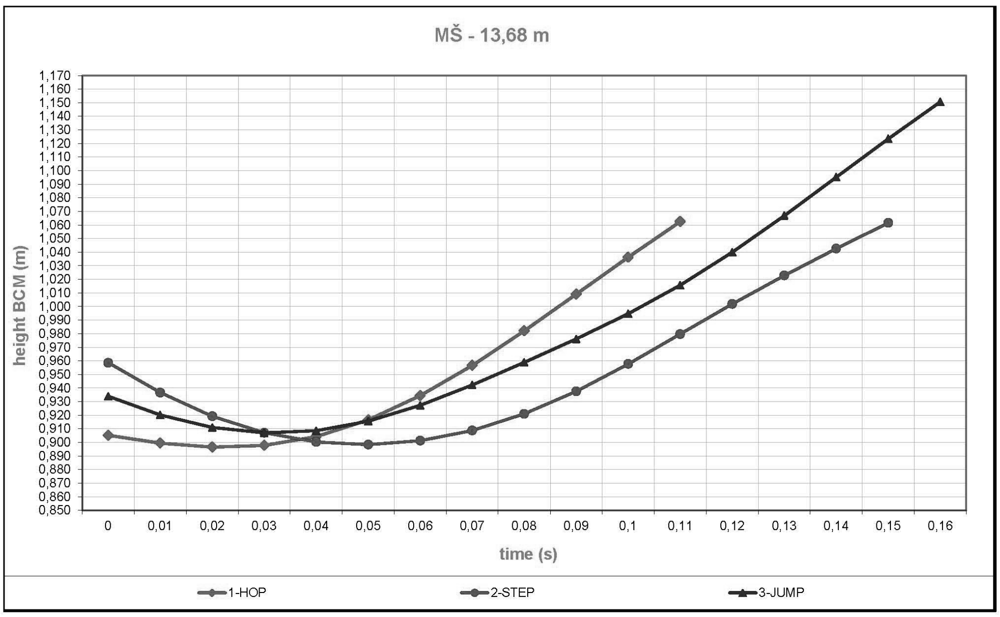
the triple jump. The study by Kyrolainen et al. (2009) showed the following average values of take-off angles of the finalists at the IAAF World Championships in Athletics, Helsinki 2005: *hop*= 15.50; *step* = 11.40 and *jump* = 21.40. In comparison, significantly higher values of these angles were noticed for the measured subject in the present study. The motor pattern of the triple jump of the measured subject to larger extent emphasised the height of individual phases, which was related to the lower horizontal velocity of the subject. Lower flight trajectories are usually characteristic of female and male jumpers with higher basic speed (Hay, 1992; Kreyer, 1993; Panoutsakopoulos & Kollias, 2008).

From the biomechanical point of view of the triple jump, the motor pattern of individual take-off actions differentiated significantly in the duration of support, horizontal velocity, take-off angle and vertical amplitude of the BCM movement. However, beside kinematical parameters, neuromuscular mechanisms of development of the reaction force of surface are even more important for the efficiency of take-off actions (Kyrolainen et al., 2009).

Take-off actions in the triple jump are the most typical motor situations, when the release of reaction

SLIKA 6

Vina centra tjelesne mase (BCM) i trajanje faze oslonca na podlogu - MŠ: 13,68 m



force of the surface combined with eccentric and concentric muscular contractions is required (Gollhofer & Kyrolainen, 1991; Komi 2000; Kyrolainen et al., 2009). From the point of view of motor strategies and motor structure, the take-off actions differentiate both in the duration as well as in kinematical and dynamic parameters. According to the duration of support part, the shortest take-off time was noticed in the take-off of the first - *hop* - phase (0.12 s) and the longest was the take-off in the last – *jump* - phase (0.18 s). Eccentric-concentric cycle in the take-off action is a result of muscle-lengthening due to external force and muscle- shortening in the second phase (SSC: stretch – shortening cycle) (Komi, 2000; Komi & Gollhofer, 1997; Nicol, Avela, & Komi, 2006). In eccentric phase a certain amount of elastic energy is stored in the muscular-tendon complex, which can be then used in the second phase. A part of elastic energy, which has been accumulated in a muscle, is available only for certain time. This time is being defined with the lifespan of muscle cross bridges and lasts between 30 to 140 milliseconds. (Cavagna, 1977; Enoka, 2003). From the aspect of force production it is important that the muscle in eccentric contraction develops as high force as possible and consumes less chemical energy than in concentric contraction (Enoka, 1998; Enoka, 2003; Komi & Gollhofer, 1997). The time of switch also influences the efficiency of eccentric-concentric contraction. The longer the switch between two types of contraction, the less efficient the contraction is. The duration of transformation from eccentric to concentric contraction is in correlation with the amortisation angle in the knee of the take-off leg (Figure 6). Small oscillation of the BCM in the vertical axis can be noticed in the measured subject, pointing to the small amplitude of angle in the knee with the maximal amortisation in the take-off action. Variation of the BCM height in the first two phases is 16 cm, whereas the difference between the highest and the lowest point of the BCM in the *jump* take-off is 24 cm in vertical axis. Beside the magnitude and the speed of change of the muscle length and the duration of switch, pre-activation is also very important for the efficiency of eccentric--concentric contraction (Enoka, 2003; Gollhofer & Kyrolainen, 1991; Komi, 2000). Pre-activation defines the first contact of the foot with the surface. The measured subject M. Š. placed her foot extremely actively in the direction down and backwards. Pre--activation suitably prepares the muscles for extension and is being manifested in the number of joined muscle cross bridges and the change of excitation of ἀ- motor neurons (Enoka, 2003). Both factors influence the larger short range stiffness. If the short range stiffness is larger, the lengthening of ligaments and tendons is more pronounced, resulting in smaller consumption of chemical energy in the muscle (Cavagna, 1977; Enoka, 2003; Komi, 2000; Komi & Gollhofer, 1997). Smaller consumption of chemical energy is particularly important in those motor situations, where a particular movement has to be carried out with large speed and the triple jump is one of the most typical examples of such movement.

CONCLUSION

The result in the triple jump, which is a complex track and field discipline, depends on combination of speed, strength, technique, visual and kinaesthetic movement control. Optimal integration of cyclic and acyclic movements ensures maximal efficiency of motor pattern. However, the motor pattern is not always consistent. Some technical elements of the model are consistent, whereas the others vary. With the use of 3-D biomechanical analysis of two triple jump attempts, the following conclusions can be made:

- the run-up velocity in the last five metres (6 – 1 m) varied significantly,
- the distance and proportion of the last two run--up strides varied and the visual control of the athlete was not optimal,
- kinematical structure of the run-up revealed a tendency of longer last stride and shorter second to last stride,
- the speed of the last two strides (L2 + L1) was different,
- athlete achieved the highest total run-up speed in the last stride,
- partial distances of triple jump phases (hop--step-jump) were relatively stable with the distance of *step* varying the most,
- in both attempts athlete used a strategy of preserving the horizontal velocity with emphasised distance of the last phase,
- good connection of individual phases was a result of optimal kinaesthetic control and dynamic balance,
- the model of duration of support and flight parts in hop, step and jump phases indicated the tendency of high stability,
- horizontal velocity varied in individual take-off actions with the largest difference noticed in step phase,
- particular reduction of horizontal velocity in take-off action of *jump* phase was a result of

emphasised increase of vertical velocity, which ensured optimal height of the flight trajectory in the last phase.

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Correspodence to:
Prof. Milan Čoh, PhD
Fakulteta za šport
Gortanova 22
10000 Ljubljana
Slovenia
E-mail: Milan.Coh@fsp.uni-lj.si
Phone: 00386 41 72 93 56