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Consistency and Variability of Kinematic Parameters in the Triple Jump

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ABSTRACT

The purpose of the study was to examine the consistency and variability of kinematical parameters in the technique used in the triple jump, one of the most complex athletics disciplines. An examination was made of two attempts of an elite female jumper performed in laboratory conditions during her preparation for the 2008 Olympic Games, where she placed 6th in the final. The Opto-track system and 3-D kinematical technology were used in to study the parameters of model technique. The analysis revealed that optimal results can be achieved with different programme motor strategies and that the motor pattern is generated by both consistent and variable parameters. The most consistent parameters of motor pattern in the subject were: partial distances of the individual phases, duration of the support phases in the take-off actions, the angles of take-off and the vertical amplitude of the body centre of mass. Variability of the motor pattern was revealed mostly in the following kinematical parameters: the velocity in the last 5m of the approach, the length and proportion of the last two approach strides, the horizontal velocity of the body centre of mass in the take-off actions.

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Introduction

From the biomechanical point of view, the triple jump is one of the most complex track and field disciplines, comprising an approach phase and three consecutive phases (known as the hop, the step and the jump) which themselves include a take-off, flight and landing. Each of the structural units represents a specific motor task with certain characteristics and requirements that the jumper must fulfil in order to execute a successful jump

Performance in the triple jump, i.e. the overall distance achieved, largely depends on the approach velocity and the optimisation of the distances of the three flight phases in relation to each other (HAY & MILLER, 1985; HAY, 1992; GRAHMAN-SMITH & LEES, 1994; MILADINOV & BONOV, 2004). According to some previous studies (CONRAD & RITZDORF, 1990; GRAHMAN-SMITH & LEES, 1994; HAY, 1999; JURGENS, 1998, PANOUTSAKOPOULOS & KOLLIAS, 2008), preservation of horizontal velocity throughout the flight phases is a crucial factor for achieving maximal distance and the critical moment for this is the transition from the hop phase into the step phase.

If we look at motor pattern structure, the triple jump can be regarded as a connection of cyclic and acyclic movements. Efficient transformation of approach velocity into the take-off for the hop phase is correlated with correct rhythm and with visual and kinaesthetic control (YU & HAY, 1996; HAY, 1999; KYROLAINEN et al., 2007). The hop is generally the longest of the three flight phases and represents 36–39% of the overall distance (GRAHMAN-SMITH & LEES, 1994; KYROLAINEN et al., 2007; PANOUTSAKOPOULOS & KOLLIAS, 2008). Efficient execution of the hop is a key element for the next two phases (step and jump) and thus the entire triple jump.

However, the exact proportion of the three phase distances depends on motor strategies adopted by jumpers. Three techniques of triple jump have been identified: “Hop Dominated”, “Hop-Jump” and “Balanced”. In the first, there is an emphasis on the distance of the first phase (hop), in the second, the emphasis is on the distance of the last phase while in the third, the jumper seeks a balance between the distances of all three phases. Distances and proportions of the different phases are defined with the execution of the support and flight phases. The transition of horizontal velocity is correlated mostly with efficient take-off action. The optimal proportion between horizontal and vertical component of the body’s centre of mass (BCM) velocity in the support phase is very important.

It seems clear that overall distance in the triple jump is a product of various types of technique, other factors and their correlations. The Bernstein Theory (LATASH, 1994) defines sports technique as a managed process with compensational and self-regulative characteristics. Although the motor pattern is standardised and automated, an athlete cannot control all the motor process phases (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, and a movement within a sports technique cannot be executed correctly without the existence of a suitable programme. An athlete possesses programmes and subprogrammes in a primary motor centre of the central neural system; they are either permanent or acquired according to the external and internal circumstances (ENOKA, 1998).

Normally, technique in elite sports performers is never final or absolute. Every athlete constantly seeks to perfect his/her technique and adapt it to numerous external and internal factors. Although the basic elements of technique are relatively stable, some subtle aspects do change. The complete stabilisation of technique is not possible due to various endogenous factors (mental status, degree of fitness, pressure, competitive stress) and exogenous factors (micro-climatic conditions: wind, outside temperature, altitude above sea level; and sports infrastructure: different structure and elasticity of the surface).

According to the Bernstein’s theory (LATASH, 1994) there are two programme strategies for the motor pattern where a high degree of movement stabilisation is required. According to the first, it is possible to realise the motor pattern by keeping the technical parameters constant. The second strategy is based on the consistency of some and variability of other technical parameters. Hypothetically, it could be expected for a result in the triple jump to be achieved with different programme strategies and with combination of various kinematic parameters in the individual technical phases.

The aim of the present study was to examine consistency and variability of technique parameters in a world-class female triple jumper. We wanted to see if such an elite athlete uses different programme strategies when executing the triple jump. Our approach was to establish which kinematical parameters vary and which are consistent from one jump to another.

Methods

The subject of the study was Slovenian jumper Marija Šestak (age: 28, height: 172cm, weight: 66.5kg), who was the bronze medallist in the 2008 World Indoor Championships, the 6th placer in the 2008 Olympic Games and the silver medallist in the 2009 European Indoor Championships. She has a personal best of 15.03m (see Figure 1).

Under laboratory conditions, measurements of her jumps were carried out during the preparation phase prior to the 2008 Olympic Games in Beijing. Six attempts were recorded and analysis was made of the two longest (attempt A, attempt B). The official distance of attempt A was 13.68m with the effective distance of 13.85 (toe-to-board distance = 0.17m). The official distance of the second attempt was 13.63m and the effective distance was 13.66m (toe-to-board distance = 0.03m). The difference in the effective distance between the two attempts was 0.19m.

OPTO-TRACK technology from the Italian manufacturer Microgate was used to measure the distances of different phases as well as the support and flight times of the strides in the approach, and in the three jump phases (hop, step and jump). The basic components of the measuring system are interlinked rods (100cm x 4cm x 3cm) with built-in optical sensors and the computer program for data recording and analysis (see Figure 2). Each of the rods contains 32 sensors – photo cells, which are positioned every 4cm and placed 0.2cm above the ground surface. The total length of the interlinked rods was 20m. The rods of the measuring system were placed on both sides of the runway (width = 1.22m). A system of infrared photocells (BROWER – Timing System) was used to measure the approach velocity (11-6m, 6-1m).

Figure 1: Marija Šestak is one of the best female triple jumpers in the world (personal best 15.03m)

Figure 2: Measurement procedures for dynami analysis of triple jump technique (Opto Track Technology)

Table 1: Consistency and variability of kinematical parameters in triple jump technique

PARAMETERS	PHASE	Attempt A	Attempt B
Result (m)		13.68	13.63
Effective distance (m)		13.68	13.66
Approach velocity (ms^{-1})	11 – 6 m	6.94	6.94
	6 – 1 m	8.20	8.77
Approach stride length (m)	2L	2.20	2.17
	1L	2.30	2.18
Approach velocity (ms^{-1})	2 L	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	34.6	34.7
	Step	29.3	28.8
	Jump	36.1	36.5
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
3 – D velocity – xyz (ms^{-1})	Hop	8.28	8.27
	Step	7.58	7.31
	Jump	6.46	6.58
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 (^{0})	Hop	19.2	17.4
	Step	14.9	15.7
	Jump	27.5	27.7
Maximal height of the C.G. (m)	Hop	1.06	1.07
	Step	1.06	1.08
	Jump	1.15	1.15
Minimal height of the C.G. (m)	Hop	0.90	0.89
	Step	0.90	0.91
	Jump	0.91	0.90

Recordings were obtained from four synchronised video cameras (SONY DVCAM DSR-300 PK) operating at a frequency of 50Hz and definition of 720 x 576 pixels, which were placed on a 90° angle to the optical axis. The first two cameras covered the area of last two strides of the approach and hop phase while the other two cameras recorded step and jump phases. To achieve better precision and for the purpose of biomechanical analysis of the take-off action in the hop and step phases, two high-speed digital cameras (Mikrotron Motion Blitz Cube ECO-1 and Digital Motion Analysis Recorder) were used. The cameras could record six seconds of movement with the frequency of 1000 frames per second and definition of 640 x 512 pixels; however, a frequency of 500 frames per second was chosen for the present study. The analysed area of the last two approach strides and the three jump phases were calibrated with a referential measuring frame (1m x 1m x 2m), whilst considering eight referential corners. The length of analysed movement has been defined with the x-axis, height with the y-axis and depth with the z-axis (see Figure 3).

For calculation of the kinematic parameters of technique, 3-D software equipment APAS (Ariel Dynamics Inc., San Diego, Ca) was used. Digitalisation of 15-segment model of the jumper's body was made; the model was defined with 18 referential points (see Figure 4).

Results and Discussion

Optimal velocity, good visual control and an optimal structure of the last three strides of the approach are basic requirements for a good triple jump result. In Table 1, it can be seen that that our subject jumper developed identical velocity (6.94 ms^{-1}) in the 11 – 6m zone prior to the take-off board in both of the analysed attempts. However, the velocity differentiated significantly in the 6 – 1m zone. Namely, in attempt B the measured velocity was greater than in attempt A by 0.57 ms^{-1}.

The structure of the last two strides (1L and 2L) also differed significantly, both in terms of stride length and frequency. In both attempts,

Figure 3: Calibration – the procedure for comparing spatial measurements from different devices

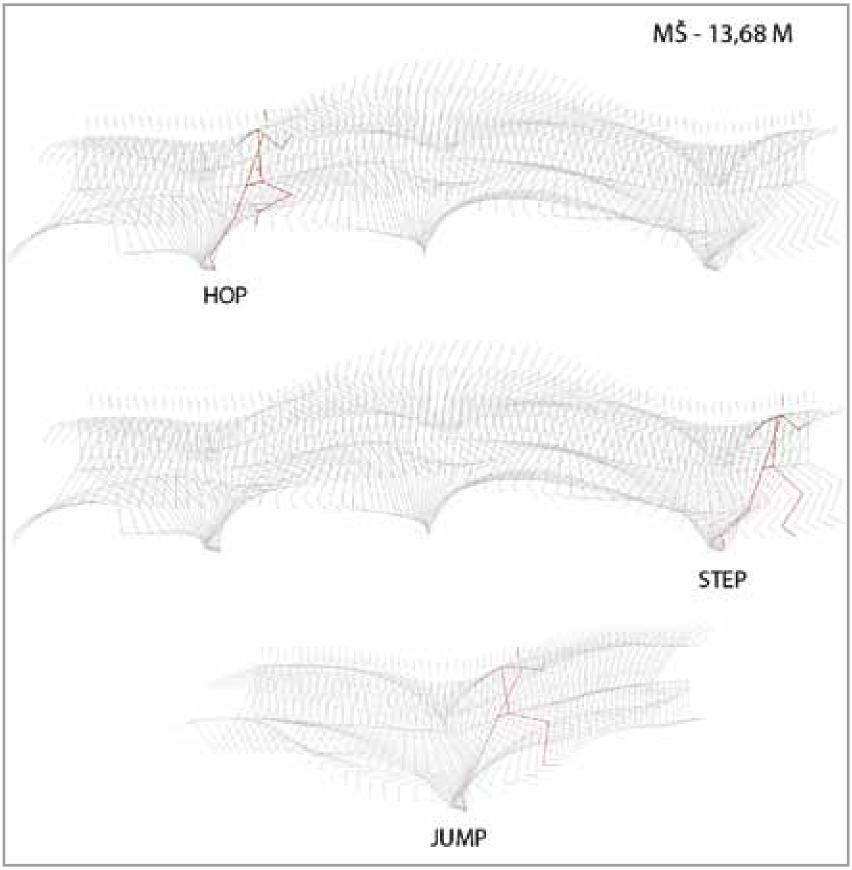

Figure 4: Kinematics of technique in the hop-step-jump phases (Marija Šestak: 13.68m)

the penultimate stride was slightly longer than the last stride. In contrast, a tendency of a longer last stride has been noticed in some other elite female triple jumpers: Savinge (CUB), Smith (JAM), Lebedeva (RUS), Rahouli (ALG), Topic (YUG). The length of the last stride is correlated with the efficient transformation of horizontal into vertical velocity, which ensures the required height of the BCM trajectory in the first jump phase (the hop).

According to the total and relative distances of the individual phases, our subject is a typical representative of the "Hop-Jump" technique, with particular emphasis on the last phase (the jump). The proportion of the partial distances of the individual jump phases did not differentiate significantly between the attempts. In attempt A the distance of the hop was 4.73m (34.6%), the step 4.01m (29.3%) and the jump 4.94m (36.1%). Apparently, the motor strategy of our subject in this phase is very stable. KYROLAINEN et al. (2009) found that on average the proportion between the different partial phases of the women's finalists at the 2005 World Championships in Athletics amounted to 36.2%:29.4%:34.5%.

The "Hop Dominated" technique is the one most often seen in both male and female triple jumpers. The characteristic of representatives of the "Hop Dominated" technique is high horizontal velocity, which is developed in the approach and the first take-off action. The characteristic of our subject is to have larger potential in elastic strength than in velocity, the former being utilised mostly in the second and third jump phases. Partial distances of the 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 (WINTER, 1990; LATASH, 1994; MCGINNIS, 1999; SCHMIDTH & LEE, 1999). Therefore, optimal proportions between partial phase distances extremely depend on individuals (HAY, 1992).

In our subject, the jump phase distances were in strong correlation with the duration of the corresponding support and flight phases. In attempt A, the duration of the support in the hop phase was 0.11 sec, in the step phase it was 0.15 sec and in the jump phase it was 0.16 sec. Support times increased with the reduction of the horizontal velocity of the BCM. Our subject 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 phases (the jump). In its kinematical structure, the jump phase is similar to the long jump. The partial contribution of the jump phase to the final result amounted to a relatively high 36.1%. In this phase, a high value for the angle of take-off (27.7^0) was seen.

The kinematic parameters of attempt B were almost identical in the duration of support and flight phases as well as in angles of take-off angles and the take-off actions for the three jump phases. The value of the angle of take-off in the jump phase differed significantly from some of the previous studies (PANOUTSAKOPOULOS & KOLLIAS, 2008; KYROLAINEN et al., 2009; MENDOZA et al., 2010). The large angle of take-off resulted in a high flight trajectory of the BCM and was manifest in the duration of the flight of the jump (0.65 – 0.66 sec).

Undoubtedly, the horizontal velocity in the individual take-off phases is a crucial generator of success in the triple jump. The smaller the decrease of horizontal velocity, the better the final result. Our subject achieved the highest horizontal velocity in her last stride (L1) in both the attempt A ($8.35ms^{-1}$) and the attempt B ($8.41ms^{-1}$). The decrease of horizontal velocity at the end of the take-off action for the hope amounted to $-0.47ms^{-1}$ (or 5.6%) in attempt A and – $0.48ms^{-1}$ (or 5.7%) in attempt B. In the 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 (Figure 5a, 5b). The difference in horizontal velocity of the BCM was noticeable only in the take-off action of step phase, which was manifested in slightly shorter partial distance of this phase in attempt B.

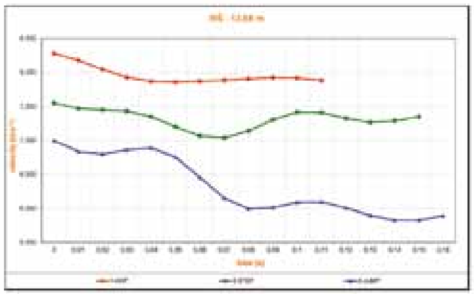

Figure 5a: Horizontal velocity of body centre of mas and the duration of support phases - 13.68m

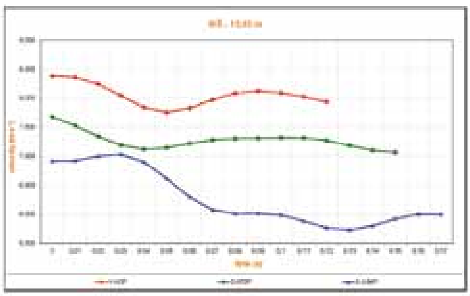

Figure 5b: Horizontal velocity the body centre of mass and the duration of support phases- 13.63m

The reduction of horizontal velocity is a result of ensuring the optimal vector of vertical velocity. Vertical velocity is the highest in the first and last jumping phases of both analysed attempts (Figure 6a, 6b). The lowest vertical velocity was recorded in the step phases (A = $1.86ms^{-1}$, B=$1.88ms^{-1}$). The basic strategy of our subject is to preserve as much horizontal velocity as possible whilst ensuring the optimal vertical velocity.

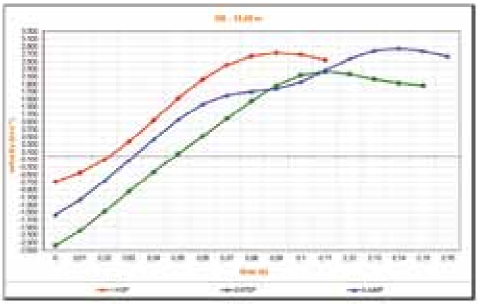

Figure 6a: Vertical velocity of the body centre of mass and the duration of support phases - 13.68m

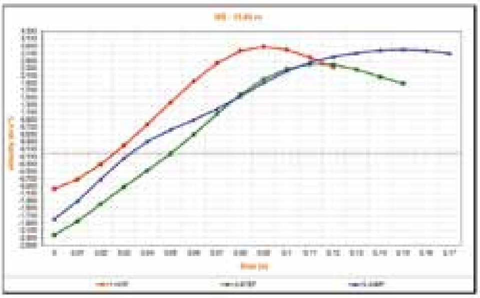

Figure 6b: Vertical velocity of the body centre of mass and the duration of support phases - 13.63m

The magnitude of vertical velocity is correlated with the angle of take-off, which was also the highest in the first and third jump phases. The study by KYROLAINEN et al. (2009) showed the following average values of angles of take-off for the finalists at the 2005 IAAF World Championships in Athletics: hop = 15.5^0 , step= 11.4^0 and jump = 21.4^0. In comparison, significantly higher values for these angles were noticed for our subject in the present study. The motor pattern of our subject to large extent emphasised the height of the individual a phases, which was related to her relatively lower horizontal velocity. Lower flight trajectories are usually characteristic of both male and female triple jumpers with higher basic speed (HAY, 1992; KREYER, 1993; PANOUTSAKOPOULOS & KOLLIAS, 2008).

From the biomechanical point of view, the motor pattern of the individual take-off actions differed significantly in the duration of support, horizontal velocity, angle of take-off 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. A small oscillation of the BCM in the vertical axis can be noticed in our 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 jump phases is 16cm, whereas the difference between the highest and the lowest point of the BCM in the jump take-off is 24cm in the vertical axis.

Conclusion

The triple jump is a complex track and field discipline in which the result depends on a combination of speed, strength, technique and visual and kinaesthetic movement control. Optimal integration of cyclic and acyclic movements ensures maximal efficiency of the motor pattern. However, the motor pattern is not always consistent. Some technical elements of the model are consistent, whereas the others vary. The purpose of the study was to find out if a female athlete at the highest international level uses different programme strategies when executing the triple jump, which of the kinematical parameters vary, and which are consistent. With the use of 3-D biomechanical analysis of two attempts, the following conclusions can be made:

- the approach velocity in the last five metres (6 – 1 m) varied significantly;
- the distance and proportion of the last two approach strides varied and the visual control of the subject was not optimal;
- the kinematical structure of the approach revealed the subject had a tendency towards a longer last stride and shorter penultimate stride;
- the velocity of the last two strides (L2 + L1) was different;
- the subject achieved the highest approach velocity in the last stride;
- partial distances of the jump phases (hop-step-jump) were relatively stable with the distance of step varying the most;
- in both attempts the subject used a strat-

egy of preserving the horizontal velocity with emphasis on the distance of the last phase;

- the subject is a typical representative of the "Jump Dominated" technique;
- good connection of individual phases was a result of optimal kinaesthetic control and dynamic balance;
- the model of duration of support and flight phases in the hop, step and jump indicates a tendency towards high stability;
- horizontal velocity varied in the individual take-off actions with the largest difference noticed in the step phase;
- a particular reduction of horizontal velocity in the take-off action of the jump phase was a result of an emphasised increase in vertical velocity, which ensured optimal height of the flight trajectory in this phase.

Although the present study has been carried out on a single athlete, the importance of the study for practice, sports science and sports biomechanics is significant. The results are particularly valuable as they were acquired with the use of the latest measuring technologies. Only a high standard of measuring procedures can ensure precise results, which can help coaches and athletes in the process of planning and control of training.

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REFERENCES

CONRAD, A. & RITZDORF, W. (1990). Scientific Research Project at the Games of the XXIVth Olympiad – Seoul 1988: final report. International Athletic Foundation, International Amateur Athletic Federation.

ENOKA, R. (1998). Neuromechanical Basic of Kinesiology. Champaign IL: Human Kinetics

ENOKA, R. (2003). Neuromechanics of human movement. Human Kinetics, Champaign, IL.

GOLLHOFER, A. & KYROLAINEN, H. (1991). Neuromuscular control of the human leg extensor muscles in jump exercises under various stretch-load conditions. International Journal of Sports Medicine, 12, 34-40.

GRAHMAN-SMITH, P. & LEES, A. (1994). British triple jumpers 1993: approach speeds, phase distances and phase ratios. Athletic Coach, 28, 5-12

HAY, G. & MILLER, J. (1985). Techniques used in the triple jump. International Journal of Sport Biomechanics, 1, 185-196.

HAY, J. (1992) The biomechanics of the triple jump: a review. Journal of Sport Science, 10 (4), 343-378.

JURGENS, A. (1996). Biomechanical investigation of the transition between the hop and step. New Studies in Athletics, 4, 29-39.

KYROLAINEN, H.; KOMI, P.; VIRMAVIRTA, M. & ISOLEHTO, J. (2009) Biomechanical Analysis of the Triple Jump. New Studies in Athletics (supplement), 57-64.

KREYER, V. (1993). About the female triple jump. Modern Athlete and Coach, 31, 13-17.

McGINNIS, P. (1999). Biomechanics of Sport and Exercise. Human Kinetics, Champaign, IL.

LATASH, M.. (1994). Control of Human movement. Human Kinetics. Publishers. Champaign, Illinois

MENDOZA, L. & NIXDORF, E. (2010). Scientific Research Project Biomechanical Analysis at the Berlin 2009 (http:/ www.osp-hessen.de)

MILADINOV, O. & BONOV, P. (2004). Individual approach in improving the technique of triple jump for women. New Studies in Athletics, 4, 27-36.

PANOUTSAKOPOULOS, V. & KOLLIAS, I. (2008). Essential parameters in female triple jump technique. New Studies in Athletics, 4, 53-61.

SCHMIDTH, R. & LEE, T. (1999). Motor Control and Learning. A behavioural Emphasis. Champaign IL: Human Kinetics

WINTER, D. (1990) Biomechanical and motor control of human movement (2nd edition). Toronto: John Willey & Sons Inc.

YU, B. & HAY, G. (1996). Optimum phase ratio in the triple jump. Journal of Biomechanics, 29, 1283-1289.