Journal of Applied Sports Science
March 2015, Volume 5, No. 1

Changes in Vertical and Leg Stiffness during Triple Jump Performance.

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Abstract

Purpose: the aim of the present study to identify changes in vertical stiffness(K_vert) and leg stiffness 〖(K〗_leg) during triple jump and identify the relationship between both vertical and leg stiffness and horizontal velocity and the loss of horizontal velocity.

Methods: Six male triple jumpers were videotaped during triple jump performance with three video cameras 60 Hz and the analysis was performed by DARTFISH TEAM PRO 4.5 software program, One-way repeated measure ANOVA was performed for each parameter. For the correlation analysis Pearson's correlation coefficients were used to examine the relationships between both (K_vertand 〖K〗_leg), and horizontal velocity and loss of horizontal velocity.

Results:K_vertreached maximum value at hop (31.42 kN/m), then decreased consistently during step (25.83 kN/m) and jump (20.33 kN/m. Decrease in horizontal velocity during step and jump was 11.3 % and 13.4% respectively. On the other hand K_leg reaches a minimum value during hope (13.77 kN/m), then peaked at step phase (25.89 kN/m) and decreased during jump (16.97 kN/m).

Conclusion: the results of the present study suggested that a higher K_vert values are necessary to maintain horizontal velocity and minimizing the loss of horizontal velocity during triple jump performance. And also K_leg plays an important role in maintaining horizontal velocity during step and jump but not in whole triple jump performance..

Introduction:

Understanding human body movement is one of the most difficult tasks in the field of scientific Research. The human body consists of many segments which move due to muscles contraction, so the biomechanical analysis is one of the most important tools that could help us to understand the human motion.

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 which are hope, step and jump [17].An elite triple jumper should be able to reach average speeds of more than 10.4 m´s-1during the last 5 m before the take-off, and to maintain as much of this speed as possible during the hop, the step and the jump [22]. This is possible only by minimizing the braking forces, thus optimizing vertical velocity. [13]

Good take-off technique is needed to provide an efficient link between muscle actions and their timing when producing large forces in the optimal direction, if horizontal speed is to be maintained. This requires the ability of the jumper to tolerate high impact forces with minimal decrease in horizontal velocity [13].also some previous studies suggested that the loss in the horizontal velocity may be a function of leg stiffness [3].

A spring mass model is often used to measure lower limb stiffness during bouncing gaits (running – hopping – trotting) Figure (1), This model consists of a body mass and linear spring (leg spring) supporting the body mass [1, 5, 21]. The leg spring is compressed during the first half of the support phase and rebounds during the second half, storing and then releasing elastic energy during these two phases [8,9].

Vertical stiffness (K_{vert}) is calculated as the ratio of the vertical leg spring compression (vertical displacement of CG) and peak vertical ground reaction force at the middle of the stance phase, while leg stiffness (K_{leg}) is defined as the ratio of the total leg spring compression and peak vertical ground reaction force at the middle of the stance phase[1,5,21], previous studies showed that (K_{vert}) is correlated with horizontal velocity, On the other hand (K_{leg}) remains constant over a wide range of running velocities[9,10,18].

It has been demonstrated that there is a significant positive relationship between K_{vert} and horizontal velocity during sprint running [10,11,15,20,24], long distance running [19] and treadmill running [18],and a significant negative relationship between K_{vert} and loss of horizontal velocity during repeated sprinting [11].However some previous studies demonstrated that there is no significant relationship between K_{leg} and horizontal velocity during sprint, treadmill and distance running [8,9,18,20,24].

previous studies on triple jump focused mainly either on kinematical analysis of the individual athlete techniques[12,14 ,17], Ground reaction forces during three take off actions[7,13] or more specific aspects of the optimum phase ratio[4,17] but until now no studies focus on changes in spring mass model characteristics during triple jump

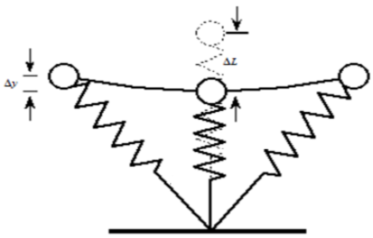


Figure (1) the model consists of a mass and a single leg spring (which joins the foot and the center of mass DL is its maximal compression. (ΔY_c) is the vertical displacement of the mass during the stance phase, and (ΔL) is the vertical compression of the leg spring during the mid-stance phase [6]

So the main aim of the present study to identify changes in vertical and leg stiffness during triple jump and identify the relationship between both vertical and leg stiffness and horizontal velocity and the loss of horizontal velocity during triple jump performance.

Methods:

- Subjects:

Six male triple jumpers with no neuromuscular disorders or functional limitations participated in the study. Their physical characteristics were: age 23.5±3.5 yrs, height 182±3.7 cm, and body weight 76.6±3.10kg, triple jump distance 15.30±0.75 (mean ±S.D).

-Data collection:

Participants in this study were filmed during national champion of Egypt 2013, each athlete had six trails but the biomechanical analysis was established for the best trail for each subject

Three video cameras 60 Hz (DCR-SR68 SONY) was used to videotape each subject according to previous studies (Milan Čoh and Otmar Kugovnik 2011) as followed: each camera was placed on a 90° angle to the sagittal plan. The first camera 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, every camera covered 9m width with height 1.15 m. the analysis was performed by DARTFISH TEAM PRO 4 software program

In the present study, flight time (*t*f) and ground contact time (*t*c) were measured For each phase using kinematic analysis, we determined leg spring stiffness using kinematic analysis. Variables calculated in the present method are similar to those reported in previous studies [13–15]. K_{vert} (kN/m) is defined as the ratio of the estimated peak vertical force (F_{max}; kN) and the estimated vertical center of mass displacement (ΔY_c; m):

$$K_{vert} = F_{max} . \Delta Y_c{}^{-1} \quad (1)$$

In the present study, we estimated both F_{max} and (ΔY_c) from body mass (in kg), flight and contact time according to the formula by Morin et al 2005

$$F_{max} = \frac{mg\pi\left(\frac{t_f}{t_c}\right)+1}{2} \quad (2)$$

And ΔY_c was calculated with the following equation

$$\Delta Y_c = F_{max} \cdot \frac{t_c{}^2}{m(\pi^2)} + g\,\frac{t_c{}^2}{8} \quad (3)$$

Where *m* is the total body mass, *g* is the acceleration due to gravity, (tf) is the flight time, and (tc) is the ground contact time at each phase.

According to Morin et al K_{leg} (kN/m) is defined as the ratio of the estimated peak force (F_{max}) and the estimated compression of the leg spring (ΔL;m) calculated from the initial leg length L (greater trochanter to ground distance in a standing position). Thus, K_{leg} was calculated as follows:

$$K_{leg} = F_{max} . \Delta L^{-1} \quad (4)$$

In the present study motion analysis method was used to determine ΔL with out using the equation of Morin et al 2005

One-way repeated measure ANOVA was performed for each parameter to determine whether there were significant differences between each phase. For the correlation analysis, each phase was used as a separate datum point. Pearson's correlation coefficients were used to examine the relationships between both (K_{vert} and K_{leg}), and horizontal velocity and loss of horizontal velocity. Statistical significance was set at $P < 0.01$, $P < 0.05$. All data are presented as mean values± standard deviation (S.D.)

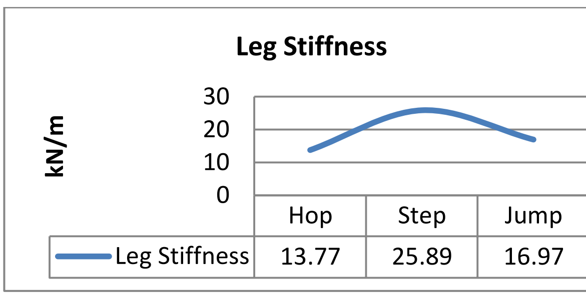
Results

Table 1 shows mean values, standard deviation (S.D.) for Spring-mass characteristics, horizontal velocity and loss of horizontal velocity for all subjects for each phase (hop – step – jump).

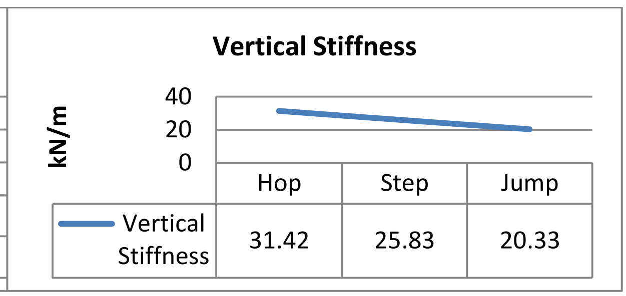
variables	Units	Hop		Step		Jump	
		M	SD±	M	SD±	M	SD±
Contact Time	sec	0.13	0.00	*0.16	0.01	*0.18	0.01
$Yc\Delta$	m	0.07	0.00	*0.20	0.02	*0.20	0.01
ΔL	m	0.16	0.02	0.20	0.01	*0.25	0.04
F_{max}	N	*2117.54	194.79	5120.78	389.53	*4109.40	349.92
K_{vert}	kN/m	31.42	5.44	25.83	2.97	*20.33	1.67
K_{leg}	kN/m	*13.77	2.45	25.89	2.35	*16.97	3.88
Horizontal velocity	m/s	9.43	0.42	*8.34	0.49	*6.99	0.66
Loss of Horizontal Velocity	m/s	0.78	0.17	*1.09	0.10	*1.35	0.23

(*) indicates significant differences from the values obtained for the best value; $P < 0.01$.

Figure (2):
Changes in Vertical Stiffness (A), Leg Stiffness (B) ,Loss of Horizontal velocity (C)and Horizontal velocity (D) during triple jump performance.



A



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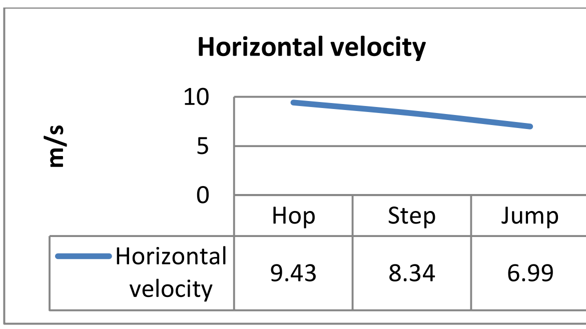

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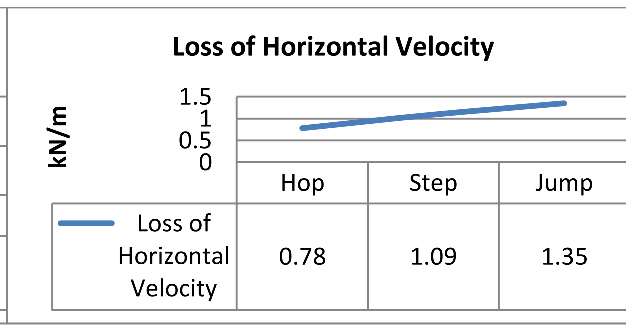

D

Table 2 shows Correlation coefficients between stiffness (K_{vert},K_{leg}) and horizontal velocity and loss of horizontal velocity. P<0.01.

	Hop		Step		jump		Triple Jump Performance	
	H V	L- H V	H V	L- H V	H V	L- H V	H V	L- H V
K_{vert}	*0.780	*-0.755	*0.898	*-0.773	*0.998	*-0.872	*0.767	*-0.795
K_{leg}	- 0.095	0.588	*0.896	*-0.941	*0.1000	*-0.985	-0.087	-0.176

K_{vert} reached maximum value at hop, then decreased consistently during step and jump 12.4 % and 15.4% respectively (Table 1).Changes in K_{vert}associated with a decrease in ground contact time, Δ Yc and horizontal velocity. Decrease in horizontal velocity during step and jump was 11.3 % and 13.4% respectively. However the loss of horizontal velocity increased during step and jump 39.7 %, 73.1 % respectively. On other hand K_{leg} reached the minimum value during hop (13.77 kN/m) then peaked at step (25.89kN/m) and decreased again during jump (16.97kN/m),but

Δ L increased consistently during step and jump % 25 and% 56.3 respectively. Also F_{max} peaked in step phase then decreased in jump 12.4%.

Table (2) represents the correlation coefficient between both K_{vert}, K_{leg} and horizontal velocity, loss of horizontal velocity for all subjects. A significant positive linear relationship was found Between K_{vert} and horizontal velocity during hop (0.780) ,step(0.898) and jump(0.998) as a separated phases and with horizontal velocity during triple jump performance (0.767).However there was a negative linear relationship between K_{vert} and loss of horizontal velocity during hop (-0.755),step (-0.755) and jump(-0.872) and with loss of horizontal velocity during triple jump performance (-0.795).

Also there was a positive relationship between K_{leg} and horizontal velocity during step(0.896) ,jump (0.1000) but there was no significant relationship with horizontal velocity with K_{leg} and horizontal velocity during whole triple jump performance. However there was a significant negative relationship between K_{leg} and loss of horizontal velocity during step and jump (-0.941), (-0.985) respectively but not during hop and whole triple jump performance.

Discussion

In the present study we examined changes of leg spring behavior during triple jump performance and determine the relationship between both K_{vert} , K_{leg} and horizontal velocity and loss of horizontal velocity

Vertical stiffness

Table (1) showed that both K_{vert} and horizontal velocity showed maximum value at hop and consistently decreased during step and jump, It has been demonstrated by previous studies that K_{vert} increases with an increase in horizontal velocity [8,9,18,20,24]. Also $K_{vert}$was significantly correlated with horizontal velocity during each phase hop 0.780 , step 0.898 and jump 0.998 as separated phases and with horizontal velocity during triple jump performance 0.767 (see Table 2).This results confirmed the result of other studies that demonstrates a significant positive relationship between K_{vert} and horizontal velocity during sprint running [10,11,15,20,24],long distance running [19] and treadmill running [18]. These results are in accordance with those of previous studies which demonstrated that changes in K_{vert} were due to fatigue. For example, Morin et al.(2006) demonstrated that K_{vert} decreased during repetitive all-out 100m sprints. In their study, as subjects became fatigued, K_{vert} decreased towards the end of the run[11]. So the results of the present study suggested that K_{vert} has an important role in maintaining horizontal velocity during triple jump performance.

Also table (1) showed a consistent decrease in both K_{vert} and horizontal velocity and an increase in both contact time and $\boldsymbol{\Delta L}$ from hop to step to jump respectively (Also Fig A , D). These results were in correspondence with results of previous studies which demonstrated that fatigue cause a decrease in stretch – shorting cycle performance that may be due to a decrease in lower limb stiffness as a result to decreasing in muscular-tendon capacity to store and release elastic energy [10,11].T.M. Comyns, A.J. Harrison, and L.K. Hennessy(2006) investigated the effect of maximal stretching shorting cycle fatigue on stretching shorting cycle performance, and they found that fatigue cause a decrease in the efficiency of the SSC behavior and that due to reduce lower limb stiffness and force production [23]

Table (2) shows a significant negative relationship between K_{vert} and loss of horizontal velocity during triple jump performance, that was agreed with results of previous studies that showed a significant negative relationship between K_{vert} and loss of horizontal velocity during bouncing gaits as sprinting and running [10,11,19] Hobara et al (2011) suggested that An increase in K_{vert} would enable the spring-mass system to recoil in a shorter time, which is beneficial for quicker absorption and generation of power and kinetic energy during ground contact [10] so in the present study K_{vert} appear to play an important role in minimizing the loss of horizontal velocity during triple jump performance

Leg Stiffness

K_{leg} reached minimum value during hop (13.77 kN/m) then peaked at step phase (25.89 kN/m)and decreased again during jump (16.97 kN/m) (as seen in fig B),these results were different from previous studies demonstrated that K_{leg} value was constant during sprint and long distance running[10,11,19].Table (2) shows a significant positive relationship between $K_{leg}$and horizontal velocity during step and jump but not with horizontal velocity during whole triple jump performance; also there was a significant negative relationship between K_{leg} and loss of horizontal velocity during step and jump but not with horizontal velocity during whole triple jump performance (see fig C). These results were somehow surprisingly because some previous studies demonstrated that there was no significant relationship between K_{leg} and horizontal velocity during sprint, treadmill and distance running [8,9,18,20,24] McMahon et al., 1987 suggest that alterations in limb posture may lead to changes in leg stiffness[16] that may be due to the change of lower limb joints during contact phase that leads to a change in lower limb position and decrease in leg spring length during landing, In addition, it is possible that the stiffness of the leg may be altered by changing the activation of muscles acting about the joints of the leg. Adamantios Arampatzis, Gert-Peter BruK ggemann, Verena Metzler (1999) reported that that it is possible to alter the leg spring stiffness by altering the running velocity and that may be due to change in ankle and knee joint angles [1]. so in the present study changes in K_{leg} during triple Jump may be due to changing in limb posture during landing that increased both ankle and knee joint stiffness .

Ground Reaction Forces

Table (1) shows the values of F_{max} during hop 2117.54 N (2.76 BW), step 5120.78 N (6.68 BW), and jump 4109.40 N (5.36 BW). Those values were somehow less than values demonstrated in previous studies[7,13], Jarmo Perttunen et al (2000) demonstrated that during triple jump vertical ground reaction force were 11.3 ± 3.6, 15.2 ± 3.3 and 12.9 ± 3.1 times body weight during hop ,step and jump respectively [13] and that may be due to differences of calculation methods or participant's level.

During hop F_{max} had the minimum value then increased during step about 58.64 % , then decreased again during jump about 19.75 % .this results are agreed with results of previous studies demonstrated that step has the largest value of ground reaction force during whole triple jump performance [7,13]Andre Luiz et al(2003) suggested that during stretch–shorting cycle activities (such as vertical jump) decline in performance after fatigue may be the result of a change in coordination (i.e., changing the neural input), (b) a change in the functional capacity of the muscles to produce force (i.e., without changing the neural input), or (c) the combination of these two factors.[2] however during triple jump the reduction in ground reaction force from step to jump may due to reduce the ability of muscle tendon complex system to tolerate impact force and a loss in the recoil characteristics of the muscles and also may be due to the decrease in both vertical and leg stiffness.

Conclusion

In the present study we examined changes of leg spring behavior during triple jump performance and determine the relationship between both K_{vert} , K_{leg} and horizontal velocity and loss of horizontal velocity. The results of the present study suggested that K_{vert} has an important role in maintaining horizontal velocity and minimizing the loss of horizontal velocity during triple jump performance. K_{leg} also plays an important role in maintaining horizontal velocity during step and jump but not in whole triple jump performance

Practical implications

- Maintaining horizontal velocity during triple jump is a function of K_{vert} which helps the triple jumper to maintaining maximum horizontal velocity and achieve maximum horizontal distance.

- During step and jump phase K_{leg} play an important rule for quicker absorption and generation of power and kinetic energy during ground contact by increasing ankle and knee joint stiffness

- Coaches should give more attention during designing training programs to improve elastic and reactive strength which has an important role in improving lower limb stiffness

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