

The effect of 8 weeks plyometric training on leg stiffness, lower limb kinematics during maximum velocity phase in young male sprinters

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Abstract

The main aim of the present study is to identify the effect of 8 weeks plyometric training on step kinematics and lower limb stiffness during maximum velocity phase in young sprinters, the research subjects was divided into 2 groups plyometric group (PG) and control group (CG), the training program was applied for 8 weeks with pre and post testing. For plyometric group, there was a significant differences between pre and posttest for step length, frequency and contact time. Also, sprint times and both vertical and leg stiffness improved significantly. However, when comparing PG and CG in posttest there was no significant differences between both groups in the post test except for ΔL for PG and that may be due to the short period of the training program. So, the researcher suggests that plyometric training is an effective method to improve sprint kinematics and lower limb stiffness considering that neural adaptation may take long time to occur more than 8 weeks.

Keywords : (plyometric training; stiffness; kinematics.)

Introduction:

Sprinting is a natural motor skill which depends on a unique motor program created in the central neural system. On the other hand, Sprinting velocity depends on many factors such as age, gender, motor abilities, inter- and intra-muscular coordination, neural factors, and optimal sprinting technique. [22]

From a biomechanical point of view, sprinting steps can be divided into two main phases, contact phase which started when foot contacts with the ground and ends when the same foot comes into contact with the ground again. However, flight phase starts when the foot loss it's contact with the ground and ends when the other foot comes in contact with the ground [19]

The most important phase of sprinting step is the contact phase, which consists of three phases, Braking phase, amortization and finally the propulsion phase (takeoff).[2,38]

Maximum velocity phase is one of the most important phases in sprinting events. During this phase step frequency reaches maximum values, and both stride length and frequency are relatively constant; so maximum velocity depends on the optimal combination of stride length and frequency. [34, 38]

By analyzing sprinting step, we find that it's one of the best examples of stretch- shortening cycle. During eccentric phase (braking phase), elastic energy is stored in the muscular-tendon system, which can then be utilized again during the concentric phase (propulsion) of sprinting step. The amortization phase (which defines as the Transition time between the two phases) must be as short as possible

and it's a limiting factor of the efficiency of stretch – shorting cycle [9, 19]

Mero et al (1986) suggested that there are many biomechanical factors that could affect the efficiency of stretch – shorting cycle (sprinting step) such as step frequency, contact and flight time and leg stiffness. So, the increase in leg stiffness enables lower limb muscular tendon system to transfer elastic energy from braking to propulsion phase as short as possible [18]

Due to the natural movement of the lower limb during support phase in sprinting step (spring like behavior), many previous studies used the spring mass model to identify the mechanics of lower limb during support phase. The spring mass model during support phase of sprinting step consists of a point of mass (equals total body mass) supported by a linear spring (lower limb) [1, 7, 26]

The most studied variable when using the spring– mass model is the leg spring stiffness. There are two different types of stiffness when studying spring mass model: Vertical stiffness (K_{vert}) which is calculated by dividing the peak of vertical ground reaction force at the middle of the support phase by the vertical displacement of the center of mass during amortization phase the other type of spring stiffness is the leg stiffness (K_{leg}) which can be defined as the ratio of the change in leg spring length and peak vertical ground reaction force at the middle of the support phase [24]. It has been demonstrated in many previous studies that both K_{vert} and K_{leg} are strongly correlated with many kinematic factors in sprinting such as stride frequency (SF), contact (T_c) [11, 5, 25, 27,37].

Figure (1)
the spring mass model of running and sprinting (Hiroki hobara et al 2009)



Plyometric training is a popular training method depending on the use of the stretch-shortening cycle during the transition from eccentric muscle contraction to concentric muscle contraction as fast as possible [12, 16, 30]. This method has a significant effect on improving the efficiency of many stretch – shorting cycle patterns such as jumping ability [13,36] acceleration [17,35] and sprinting ability [6]. Limited studies have been focused on the effect of plyometric training on leg stiffness ,for example Hirayama et al (2017) examined the effects of 12 weeks of plyometric training on stretch–shortening cycle (SSC) performance and muscle strength, tendon stiffness, and they found that there was an increase in tendon stiffness and jumping ability and they suggested that the increase in tendon stiffness and jumping performance may be a result to increase the efficiency of the energy storage and recoil process in stretch shorting cycle which result in an increase in jump performances [10]

Also, limited previous studies have been focused on the effect of plyometric training on leg stiffness of youth athletes. For example Rhodri S. Lloyd et al 2012 studied the effect of 4 weeks of plyometric training program on both reactive strength index (RSI) and leg stiffness in young athletes in 3 different age groups 9, 12 and 15 years old [14], they found that after the training program only 2 groups of 12 – 15 years old had a significant improvements in leg stiffness and The 9-year-old group didn't any make significant increase in leg stiffness. They concluded that the improvement in RSI and leg stiffness depends on age stage during this age group.

Although many of previous studies has been focused on studying sprinting kinematics in children [4,20,23,32], physiological adaptation of sprint training on youth athletes [3,29] age related changes during short sprinting [32] and the effect of different training methods on improving sprinting, agility, power and technical skills in children and youth athletes [33,8,31] no previous studies focused on the effect of plyometric training on mechanical stiffness and sprinting kinematics for youth athletes. So, the main aim of the present study is to identify the effect of 8 weeks of plyometric training on leg stiffness and lower limb kinematics during maximum speed phase in young sprinters (12 – 15 years old)

Materials and Methods

Subjects and experimental design:

Twelve (12) youth male athletes (13.92 ± 1.7 y; 1.65 ± 0.0.7 m; 57.53 ± 5.61 kg) were participated in this study. The research subjects were part of sprint and

hurdle, jumping team of Alexandria sporting club. They were divided into two groups: plyometric training group (PG) and control group (CG). Data were collected during 40m time trail before and after the applied program (8 weeks)

Data collection

Kinematic data collection:

After an appropriate warm up (30 minutes) the research subjects were asked to run 40m time trail with maximum effort from standing start The data collection was established using one video camera 50 f/s model Panasonic, the camera was setup perpendicular to the middle of a 10 m field of view (between 25m – 35m maximum velocity phase) the camera height was 1.10m ,the kinematic data for the present study was chosen according to the previous studies [27,28,30,37] step length, step frequency, contact and flight time, step velocity and average velocity. The analysis of kinematic data was performed by kinovea 0.8 motion analysis software program

Vertical and leg stiffness data collection:

Vertical stiffness:

Kvert (kN/m) is the ratio of the calculated peak vertical force (Fmax ; kN) and the vertical displacement of center of mass (ΔYc; m): [25]

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

The calculation of Fmax and (ΔYc) is calculated from body mass (in kg), flight time (tf) and contact time (tc) according to the following equation of Morin et al

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

2005.[25]

In the present study, both flight time (tf) and ground contact time (tc) were measured for one sprinting step using kinematic analysis ΔYc 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 presenting the total body mass, g is the acceleration of gravity,(tf) is the flight time, and(tc)is the contact time.

Leg stiffness:

K_{leg} (kN/m) is the ratio of the calculated peak force (F_{max} ; kN) and the change in leg spring length (ΔL ; m) which calculated from the total leg length L (from greater trochanter to ground in the standing position). So, K_{leg} was calculated as the following equation: [25]

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

leg spring stiffness was determined using kinematic analysis. Variables calculated in the present method are similar to those reported in previous studies. In the present study we use motion analysis to determine

ΔL without using the equation of Morin et al 2005 [25].

The training program:

Both PG and CG had the same sprint training program The training program was conducted for 8 weeks, 3 training units per week, however, for the experimental group, the plyometric training protocol consists of 5 body weight plyometric exercises as followed: squat jump, successive

long jump, foreword single leg hop, alternative lunge jumps and stiff knee foreword jumps (jumping foreword with minimum knee angle) the training protocol was started in the first 2 weeks by 3 sets x 6 repetition for each exercise then there was a gradual

increase in training volume during the next 2 weeks 3 sets x 8 repetitions and in the 5th week there was a decrease in training volume 3 x 6 repetitions and increased again during both the 6th and 7th weeks 3 x 8 and decreased again to 3 x 4 repetitions in the last week.

Results: Discussion:**Step kinematics:**

The main purpose of the present study is to identify the effect of plyometric training on leg stiffness and lower limb kinematics in young male sprinters. Table (1) shows results of step kinematics for research subjects before and after the training program. Values of step kinematics were similar to the results of previous studies that examined sprint kinematics of young male sprinters [23, 32, 20]

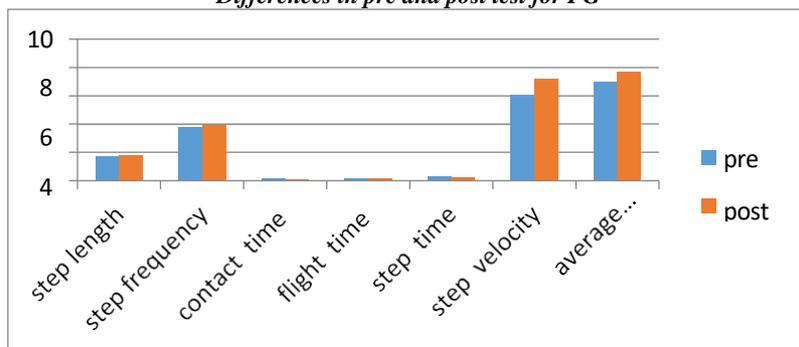
Table (1)
T paired test of step kinematics for both PG and CG before and after the training program

Variables	Units	PG						CG					
		Pre		Post		P	%	Pre		Post		P	%
		M	SD±	M	SD±			M	SD±	M	SD±		
step length	M	1.73	0.08	1.83*	0.08	*8.53	6.08	1.81	0.09	1.82	0.09	0.20	0.28
step frequency	Step/s	3.78	0.22	3.97*	0.18	*7.43	5.03	3.62	0.19	3.70	0.25	1.84	2.30
Contact Time	sec	0.14	0.01	*0.12	0.00	*4.57	13.41	0.13	0.01	0.13	0.01	1.00	1.28
Flight time	Sec	0.15	0.02	0.14	0.02	*3.16	8.89	0.15	0.02	0.14	0.02	1.46	6.67
step time	Sec	0.29	0.03	0.26*	0.02	*4.84	11.05	0.28	0.03	0.27	0.03	1.78	4.17
step velocity	m/s	6.08	0.82	7.20*	0.53	*6.01	18.41	6.48	0.84	6.82	0.75	2.08	5.14
Average velocity	m/s	6.98	0.35	7.73*	0.34	*7.32	6.08	6.61	0.94	6.70	0.80	0.44	1.39
40 m time	Sec	5.85	0.17	*5.60	0.21	*8.53	4.41	5.93	0.48	5.88	0.52	0.20	0.93

In the present study, there were no significant differences between PG and CG in any of step kinematics or spring mass model characteristics at the Pretest (baseline). For PG, step velocity increased significantly ($p = 6.01$) after the plyometric training program, while there was no change in flight time in posttest. Milan Čoh, Vesna Babić, Krzysztof Maćkała

(2010) reported that maximum speed running is a function of both step length, frequency, any change in each or both of those variables will affect average sprint velocity ($p=7.32$) [22] table (1) show a significant increase in both step length and frequency in posttest ($p= 8.53, 7.43$ respectively). While there were no change in any of step kinematics for CG

Figure (2)
Differences in pre and post test for PG



Also, table 1 shows a significant decrease in contact time for PG in the post test ($p = 4.57$) but not for CG. Mero et al (1992) and Young, M., & Choice, C. (2007) suggested that contact time is a limiting factor in maximum speed phase [19, 38]. The decrease in contact time would result in decreasing step time so step velocity will increase while maintaining flight time.

Robert G. Lockie et al (2010) reported that after a 6 weeks of plyometric training of young soccer players there was a significant improvement in step length – frequency – contact time [15], the increase in step length in the present study (6.08 %) may be due to an improvement in force application techniques (there was no significant change in GRF value for PG or CG see table 3), on the other hand, the decrease in contact time may be due to an improvement in

neural factors or an improvement in stretch and short cycle efficiency such as Kvert and Kleg as a result of plyometric training shows in table 2. Also, Table 1 shows a significant improvement in 40m sprint time for PG while there was no change in CG. Thomas nesser et al (1996) suggested that. plyometric exercises (such as horizontal, vertical jumps and hops) are a very important method to improve sprinting ability and 40m sprint time in young male sprinters [29]. The improvement in sprinting velocity may be due to the neuromuscular adaptations as a result of variety types of plyometric training such as vertical, horizontal directions and single, double contact exercises which may lead to improve neural factors (including motor units recruitment, firing rate, and inter – intra muscular coordination)

Table (2)
T paired test of spring mass model characteristics for PG and CG after the training program

Variables	Units	PG						CG					
		Pre		Post		P	%	Pre		Post		P	%
		M	SD±	M	SD±			M	SD±	M	SD±		
ΔYC	M	0.05	0.01	0.04*	0.00	4.85*	23.58	0.05	0.01	0.05	0.01	1.35	2.77
ΔL	M	0.12	0.01	*0.11	0.01	*3.87	8.11	0.12	0.01	0.13	0.01	0.54	0.00
Fmax	N	916.76	67.00	943.9	79.56	1.40	2.96	944.3	145.90	941.86	159.87	0.16	0.26
Kvert	kN/m	17.43	3.52	23.28*	2.88	*3.86	33.58	19.93	4.99	20.73	6.43	0.88	0.81
Kleg	kN/m	7.51	1.12	8.40*	1.33	*3.44	11.85	7.71	1.31	7.54	1.32	0.61	2.12

$p < 0.05 = 2.57$

Table 2 shows a significant improvement in both Kvert and Kleg for PG and a significant improvement in $Yc\Delta$ and ΔL this may be due to the effect of plyometric training on neuromuscular system. previous studies reported that a 12 weeks of plyometric training leads to an improvement in SSC efficiency by improve muscle–tendon system behavior which works as a linear spring which leads to an

increase in tendon stiffness [10] that may explain the improvement of leg stiffness and step kinematics for PG. Hiroki hobara et al (2009) reported that Kvert strongly correlated with sprinting performance and speed endurance [11]. Also, Chelly, S. M., & Denis, C. (2001) identified that Kvert is a limiting factor of maximum velocity phase [5]

Table (3)
t test of step kinematics for PG and CG after program

Variables	Units	PG		CG		P
		M	SD±	M	SD±	
Step length	M	1.83	0.08	1.82	0.09	0.37
Step frequency	Step/s	3.97	0.18	3.70	0.25	2.11
Contact Time	sec	0.12	0.00	0.13	0.01	1.76
Flight time	Sec	0.14	0.02	0.14	0.02	0.31
Step time	Sec	0.26	0.02	0.27	0.03	1.05
Step velocity	m/s	7.20	0.53	6.82	0.75	1.03
Average velocity	m/s	7.73	0.34	6.70	0.80	*2.89
40 m time	Sec	5.60	0.21	5.88	0.52	1.23

p<0.05=2.23

Figure (2)
Differences in step kinematics of post test for PG and CG

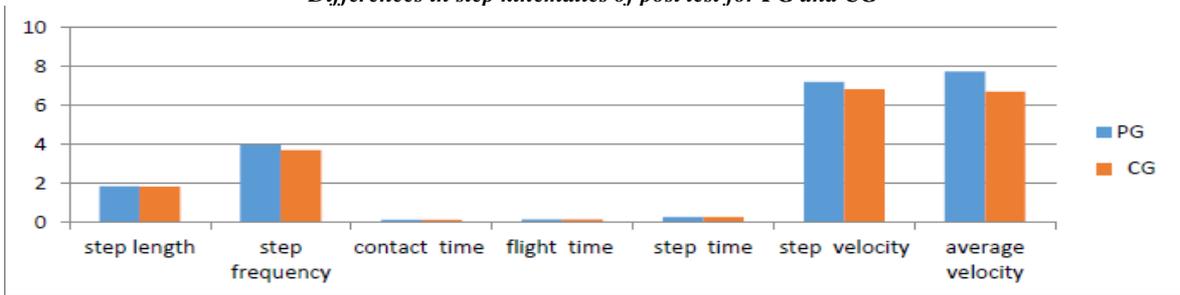


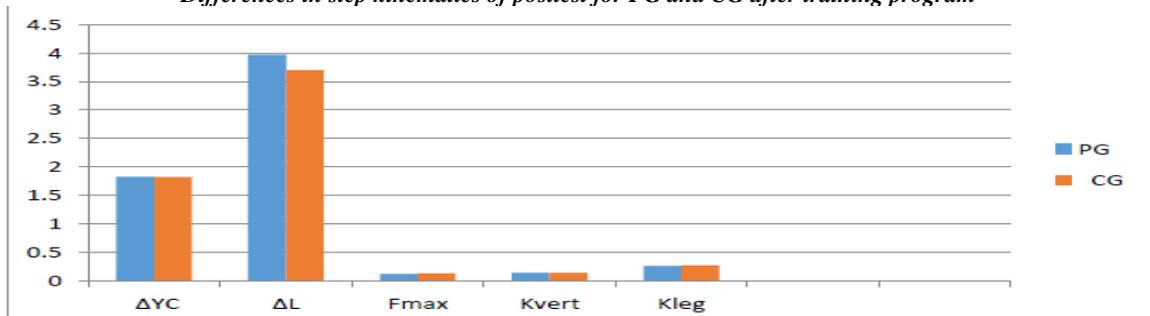
Table (4)
The effect size of the test results (N= 10)

Variables	Units	PG		CG		P
		M	SD±	M	SD±	
ΔYC	m	0.04	0.00	0.05	0.01	0.73
ΔL	m	0.11	0.01	0.13	0.01	*2.44
Fmax	N	943.93	79.56	941.86	159.87	0.03
Kvert	kN/m	23.28	2.88	2.73	6.43	0.88
Kleg	kN/m	8.40	1.33	7.54	1.32	1.13

p<0.05=2.23

However, table (3) shows no significant differences in any of step kinematics between PG and CG except for average sprinting velocity (p = 2.89) after the training program. This is due to the effect of the plyometric training program, PG subjects tend to increase their sprinting velocity in the post test by maintaining short contact time and increase step frequency (almost significant p=2.11).

Figure (4)
Differences in step kinematics of posttest for PG and CG after training program



Also, there was no significant differences in any of spring mass model characteristics between PG and CG except ΔL ($P= 2.44$) after plyometric training program. Although it is difficult to explain the result, it could be result of the relative short time of the training program previous studies on plyometric training show relatively long-time programs 10 – 12 or 16 weeks so, the relative short time for the application of the present study may be the reason of the decrease of the amount of improvement of research subjects. on the other hand, the improvement of ΔL may be due to the effect of plyometric training on muscular tendon stiffness, leg muscular tendon system acts like a linear spring during support phase so as a result of plyometric training there will be a neural adaptation of muscular

Conclusions:

The main aim of the present study is to identify the effect of 8 weeks of plyometric training on lower limb stiffness, step kinematics and sprinting performance in young male sprinters .the result of the present study suggested that plyometric training is a powerful tool to improve step length and contact time, and improve both vertical and leg stiffness by decrease ΔL while maintaining F_{max} values

system to absorb the impact during contact phase which leads to a decrease in ΔL during contact phase. Kuniaki Hirayama et al (2017) suggested that the magnitude of power or the mechanical work generated by the muscular tendon system during contact phase depends on muscular strength and lower limb stiffness, in addition to the neuromuscular activity during sprinting and jumping activities[10], so after the training program the resistance of lower limb to ground reaction force (GRF) may increase during contact phase while there was no significant difference between pre and posttest in GRF in both PG or CG which explain the improvement in both vertical and leg stiffness in PG .

relatively constant and improving 40m sprinting time by increasing step frequency for PG but when comparing both PG and CG there was no differences between any of them in sprint kinematics and lower limb stiffness except for ΔL . so the researcher suggests that plyometric training is an effective method to improve sprint kinematics and lower limb stiffness considering that neural adaptation may take long time to occur more than 8 weeks

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