Research
ISSN 2413-0516

Effect of Countermovement and Arm Swing on Vertical Stiffness and Jump Performance

Azadeh Shadmehr[a*], S. Maryam Hejazi[a], Gholamreza Olyaei[a], Saeid Talebian[a]

[a]Department of Physical Therapy, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran.
Correspondence to A. Shadmehr (email: shadmehr@tums.ac.ir)
(Submitted: 28 October 2015 – Revised version received:17 December 2015 – Accepted: 3 February 2016 – Published online: 26 March 2016)

Objectives To determine the effect of using arm swing and countermovement on vertical stiffness and maximum vertical jump performance.
Participants A total of 25 young healthy females were participated in the study. They stood on the force plate and performed two models of squat jump with (SJA) and without arm swing (SJ) and two models of countermovement jump with (CMJA) and without arm swing (CMJ). Main outcome measures: Vertical leg stiffness, jump height, flight time, contact time and power were compared in SJ, SJA, CMJ and CMJA.
Results In the CMJs, the stiffness and jump height were significantly higher than SJA and SJ. Contact time in jumps with countermovement and/or arm swing was three times lower than SJA and SJ.
Conclusion Vertical stiffness and performance parameters can be improved by using countermovement and arm swing during vertical jump and due to enhancement in work output and ground reaction force.
Keywords vertical stiffness, countermovement, arm swing, jump height

Introduction

During running or jumping, body's musculoskeletal system, including muscles, tendons and ligaments are acted together, so that the whole system behaves like a spring. As a result, these behaviours can be explained using a spring–mass model, consisting of a lower extremity as spring and a point mass as body mass.[1,2] The leg spring compresses and then lengthens during the ground contact phase, as lower limb joints flex and then extends. The stiffness of the leg spring represents the stiffness of the whole system during the ground contact phase.

Lower extremity stiffness can affect the response of body to the environment's perturbations. For assessing this parameter, there are different methods and different functions. Vertical stiffness (K_{vert}) represents the vertical displacement of center of mass (CoM) at the middle of the stance phase during hop in place or vertical jump.[1–4] Cavagna (1975) explained that displacement of CoM was determined from double integration of the force–time curve in vertical axis derived from force plate's data.[4]

Jumping is a functional task that frequently has been used in daily living activity or sport activities. Till now, hopping and drop jump frequently have been used for assessment of stiffness but there was lack of adequate evidence about investigating maximum vertical jump as a high demand activity for assessing vertical stiffness. Only one study has investigated the contribution of stiffness to vertical jump performance.[5] The study of Laffaye et al. (2005) has shown that enhancement in jump height will result in lower stiffness.[5] These results were in contradiction with Farley et al. (1991), which reported that during hopping stiffness increases due to increase in hopping frequency or hopping height.[1] It seems that there was no cut-off for the amount of stiffness. High stiffness is related to bony injuries and low stiffness is related to soft tissue injuries.[6] Understanding the effect of jump performance on stiffness would be expected to augment the efficiency as well as reduce the sport injuries.

Arm swing and countermovement were the strategies used in jumping to improve jump performance. The effects of these mechanisms on jump performance have been studied before.[7–10] These techniques are accompanied with increase in ground reaction force (GRF) and work output. Although the influences of both arm swing and countermovement on jump performance have been examined by many researchers, the contribution of stiffness to perform in countermovement jump (CMJ) and with arm swing (CMJA) is still unknown. The purpose of this study was to investigate how the combinations of both strategies can affect vertical stiffness and maximum vertical jump performance.

Methods

Subjects

Twenty-five young healthy females with no training experience participated in this study. Their mean (SD), age, weight, height and body mass index (BMI) were 22.6 (1.67) years, 55.92 (5.36) kg, 162.48 (3.94) cm and 21.46 (1.83) kg/m^2, respectively. The exclusion criteria were lower extremity abnormalities, previous leg injury, fracture, surgery and balance impairment. All the subjects signed the consent form and then entered in the present study and the project was approved by the ethics committee of Tehran University of Medical Sciences.

Jumping protocol

Squat jump (SJ): Subjects were instructed to dip to ~110° knee flexion, with their hands on their iliac crests, maintain that position and the examiner counted out 2 s on the call of examiner, the subject jumped as high as possible.

Squat jump with arm swing (SJA): For using arm swing, subjects started SJ with extended arms and swing them at once the jumping motion had been initiated.

Countermovement jump (CMJ): The subjects started the jump while their hands were on their hips, they were instructed to, with call of examiner, they dip to ~110° knee flexion as quickly as possible and then jump as high as possible.

Countermovement jump with arm swing (CMJA): For using arm swing, subjects started CMJ with extended arms and swing them at once the jumping motion had been initiated.

Procedures

K_{vert} and performance parameters were assessed within one session and to determine reliability for seven subjects, test repetitions were performed in another session that was 24 h later. Testing took place at same time of day and same room. Before the test, participants performed enough practice jumps to warm up and familiarised with the procedure. A time up to 5 min was given between practices and jump tests. After that, they were asked to perform randomised maximal jumps with 2 min of rest for prevention of fatigue, from a force platform (9090, Kistler, USA).

The following variables were calculated with this information: mean and peak force; peak power and flight time. From the force platform, the center of pressure (COP) and the vertical components of GRF were obtained.[4] The displacement of the CoM of the body at time *t* was calculated from double integrating of acceleration of CoM.

The jump height was determined by using flight time according to the formula of

Jump height (cm) = $1/8\ gt^2$,

where g = acceleration due to gravity (9.81 ms^{-1}) and t = flight time of the jump(s).[11]

For this equation, the body position in the moment of take-off and landing must be the same. Subjects were need to extend their hip, knee and ankle joints at initial ground contact of landing.[12,13] Power was measured as rate of force changes during contact time.[13]

Statistics

After data collection, means and standard deviations were calculated. The reliability of procedures was calculated utilising four methods. The Pearson product moment (PPM), the intraclass correlation coefficient (ICC) and its associated 95% confidence interval, the standard error of measurement (SEM) and the paired *t*-test were determined as outcome measures for reliability and reproducibility. A repeated measures analysis of variance was used to examine the effect of countermovement and arm swing. Post-hoc contrast (Bonferroni) was used to examine differences among the groups. Significance of tests was accepted at an alpha level of 0.05.

Results

It can be observed from Table 1 that there was very good reliability in all four jump types (PPM > 0.93, ICC > 0.91, SEM < 0.01). The vertical stiffness response to use of countermovement and arm swing can be observed in Table 2. Mean vertical stiffness of subjects significantly was increased from 9.88 ± 2.17 to 11.02 ± 2.39 kN/m across four types (Table 2). Mean jump height of subjects showed significant increase from 0.199 ± 0.025 to 0.245 ± 0.26 m across four types (Table 2). Besides, for flight time, an enhancement across all four types was seen from 0.336 ± 0.031 to 0.35 ± 0.032 s (Table 2). Mean contact time of subjects across four jump types significantly was decreased from 0.177 ± 0.039 to 0.157 ± 0.033 s (Table 2). Mean power of subjects showed no significant differences between the four jump types (Table 2).

Discussion

The purpose of this study was to determine the effect of countermovement and arm swing on vertical stiffness and jump performance and thereafter to establish the relationship between them.

An enhancement in vertical stiffness was observed across four types of jump (SJ < SJA < CMJ < CMJA), see Fig. 1. Some

Table 2. **Comparison of mean (SD) for vertical stiffness (K_{vert}), jump height (JH), flight time (FT), contact time (CT) and power (P), among SJ, SJA, CMJ, CMJA**

Variables	SJ	SJA	CMJ	CMJA
K_{vert}(kN/m)	9.88 (2.17)	10.33 (2.09)	10.47 (2.34)	11.02 (2.39)
JH (m)	0.139 (0.021)	0.141 (0.022)	0.142 (0.021)	0.155 (0.021)
FT (s)	0.338 (0.031)	0.342 (0.025)	0.348 (0.022)	0.35 (0.032)
CT (s)	0.085(0.019)	0.084 (0.015)	0.084 (0.017)	0.078 (0.016)
P (kNm/s)	718 (244.03)	725.49 (224.48)	778.5 (225.24)	733.55 (232.30)

SJ: squat jump; SJA: squat jump with arm swing; CMJ: countermovement jump; CMJA: countermovement jump with arm swing.

Table 1. **Pearson product moment (PPM), intraclass correlation coefficient (ICC), lower and upper confidence limits, paired *t*-test and standard error measurement (SEM) for different jump types (N = 7)**

Variables	Jump types	PPM (sig)	ICC	Confidence limits %	Paired *t*-test	SEM
K_{vert} (kN/m)	SJ	0.96(0.008)	0.94	0.53–0.99	0.78	0.007
	SJA	0.99(0.004)	0.98	0.77–0.99	0.6	0.001
	CMJ	0.97(0.000)	0.97	0.69–0.99	0.36	0.004
	CMJA	0.92(0.016)	0.94	0.39–0.99	0.14	0.011
JH (m)	SJ	0.98(0.007)	0.97	0.26–0.99	0.31	0.002
	SJA	0.97(0.13)	0.91	0.65–0.98	0.81	0.009
	CMJ	0.99(0.000)	0.98	0.63–0.99	0.28	0.000
	CMJA	0.92(0.004)	0.96	0.15–0.99	0.19	0.003

K_{vert}: vertical stiffness; JH: jump height; SJ: squat jump; SJA: squat jump with arm swing; CMJ: countermovement jump; CMJA: countermovement jump with arm swing.

previous studies have reported that augmentation in work output and GRF occurred by using countermovement and arm swing. Stiffness directly associates to the force changes, so enhancement in reaction force can augment the amount of that.[9,7,14] Increase in jump height also can increase the stiffness.[3]

In our study, jump height increased with using countermovement and arm swing. Similar findings have been reported by other studies, during performance assessment.[9,14,7]

Lees et al. (2004) have reported that during CMJ, because of greater work output of the hip extensor muscles, the jump height was higher in CMJ than SJ.[7] On the other hand, GRF was increased by utilising the arm movements. The higher GRF caused an increase in ground reaction impulse which was the reason for the enhanced jump height.[9]

Ziv & lidor (2010) have been reported that augmented jump height in CMJ was associated with the stretch-shortening cycle (SSC).[15] With using CM, the contractile components store and release energy during eccentric and then concentric phases of jump. Some studies investigated the effect of arm swing and have seen an enhancement in GRF and net impulse.[9,15]

Our results about flight time are similar to other studies which reported the augmentation in this parameter, with increased jump height.[16,17] Countermovement and arm swing can augment the energy stored and displacement of CoM, and so the enhancement occurs in time for transformation of energy or flight time.[18] Arampatzis et al. (2001) have reported that by increasing the rate of force change during jumps the contact time after landing becomes shorter.[19]

In our study, no significant differences between the powers of four types of jump were found. Samozino et al. (2008) have reported that power was related to velocity rather than jump height and Arampatzis et al. (2001) reported that power was related to force rather than stiffness.`

Our study showed that, with higher levels of performance, from SJ to CMJA, and increment in force production and work output, there was an enhancement in the amount of stiffness. People utilise different mechanisms for performing maximum vertical jump. Based on our research, countermovement and arm swing can positively affect the performance and vertical stiffness. It seemed to be with change in level of activity and need to force production, the body adjusts stiffness and led to change in the amount of resistance against reaction forces and maintain efficiency of system.

Acknowledgement

The authors would like to thank all the subjects who participated in the experiment. This study was a part of an MSc thesis and sponsored by Tehran University of Medical Science. The authors would like to acknowledge the assistance of the faculty and staff of the School of Rehabilitation, TUMS.

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