THE ADJUSTMENT OF LEG STIFFNESS DURING DYNAMIC EXERCISE AND DOWNWARD STEPPING FOR ELDERLY

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The purpose of the present study was to evaluate the ability of leg stiffness regulation during downward stepping and maximal Counter-Movement-Jump (CMJ) for the elderly. Ten healthy aged people (age: 68.6±5 years; height: 165.3±4.4cm; mass: 61.7±9.3kg) and 10 students (age: 24.3±2years; height: 171.5±4.6cm; mass: 65.9±8kg) volunteered as subjects. Kistler force platform (1200Hz) and Peak high-speed camera (120Hz) were used synchronously to record the ground reaction force and the kinematic parameters of the subjects performing CMJ and stepping down from different heights. The results revealed that the elderly group has a smaller joint range of motion and greater leg stiffness than the young group during stepping down. The force and the leg stiffness during CMJ were significantly smaller for the elderly. The leg stiffness during downward stepping is independent of dynamic leg stiffness during CMJ. With aging, the adjustment ability of leg stiffness for maximal dynamic voluntary contraction was decreased.

KEY WORDS: elderly, stiffness, downward stepping, CMJ.

INTRODUCTION: The initial defense mechanism mediating the motor reactions to perturbations leading to fall is stiffness: the dynamic interaction between the joint displacement and force. Corrective motor response to perturbation occurs in 50 to 200 ms and the nervous system must regulate stiffness (Houk, 1979). Stiffness properties of the musculoskeletal system can be controlled by regulating muscle activation and neural feedback gain. In young subjects it was reported that muscle activity is initiated about 100 ms before touch down during downward stepping and that the deceleration during impact was associated with a preprogrammed neuromuscular activity (Rapp & Gollhofer, 1994). However, the research results concerning the stiffness as a fundamental aspect of age-associated change are discrepant because of different controlled conditions. It has been shown that elderly compare to young people executed downward stepping with greater leg stiffness and less ankle and knee flexion (Hortobagyi *et al*, 1999, 2000). Elderly people elevate muscle pre- and co-activity during downward stepping to stiffen the leg in compensation for impaired neuromotor functions. The purpose of present study was to i) evaluate the ability of leg muscular stiffness regulation during downward stepping and maximal CMJ and, ii) to investigate the relationship of stiffness regulation during dynamic exercise CMJ and downward stepping for the elderly.

METHODS: Ten healthy aged people (age: 68.6±5 years; height: 165.3±4.4cm; mass: 61.7±9.3kg) and 10 students (age: 24.3±2years; height: 171.5±4.6cm; mass: 65.9±8kg) volunteered as subjects. All subjects were apparently healthy and the elder subjects had exercise habit (2-3 times a week) preceding the study. Subjects were asked to perform the CMJ and the downward stepping from different heights: 20, 30 and 40cm. Kistler (model 9281, 60x90cm) force platform (sample rate: 1200Hz) and Peak Performance high speed camera (120Hz) were used synchronously to record the ground reaction force and the video image of the movements. The synchronization was realized by sending out a trigger-out signal from Kistler system to Peak system. The video was then digitized by Peak Motus 2000 System and the data were smoothed by Butterworth 4^{th}-order zero lag digital filter, cut-off frequency was chosen by using Optimal Method with Prescribed Limit (Peak Motus 6.0 User Manual, 2000; Winter, 1990). Leg muscular stiffness was defined in the present study as: i) the ratio of maximal ground reaction force (F_{max}) and the leg displacement (X_{max}) from ground contact to the occurrence of F_{max} during downward stepping (F_{max}/X_{max}); ii) the ratio of ground reaction force (Fi) at the moment of lowest position of the center of mass (c.m.) and the vertical displacement (Δy) of c.m. from the beginning of the movement to the lowest position of c.m. during CMJ ($Fi/\Delta y$). For the downward stepping, parameters were compared between the young and elderly group and among the different heights by two-way repeated ANOVA using SPSS software. Post hoc analysis was conducted by Tukey Significant Difference Test to evaluate the significant mean differences. For the CMJ, independent T-test was used to compare between the young and elderly group. The level of statistic significance was set at $P<0.05$.

RESULTS AND DISCUSSION: *Downward stepping from different heights-* Table 1 shows the results of statistical analyses for selected parameters: the maximal ground reaction force (F_{max}), the leg displacement (X_{max}) at the moment of maximal ground reaction force, maximal knee angular displacement ($\Delta\theta_k$), leg stiffness (Stif) from different height for elderly and young group.

Table 1. Mean values (with SD) and statistical analyses for selected parameters.

Groups	Drop Height [cm]	Fmax + [BW]	Xmax*+ [cm]	$\Delta\theta_k$ *+ [deg]	Stif * [kg/cm]
	20	2.03 (0.40)	5.7 (1.4)	18 (8.1)	22.09 (7.0)
Elder	30	2.69 (0.51)	7.6 (2.1)	23 (6.5)	22.24 (10.7)
(n=10)	40	3.32 (0.68)	8.57 (2.5)	26 (3.9)	24.19 (11.8)
	20	1.94 (0.33)	7.3 (1.9)	20 (5.6)	17.64 (9.7)
Young	30	2.86 (0.30)	9.1 (1.8)	29 (5.9)	20.84 (3.3)
(n=10)	40	3.21 (0.38)	9.7 (1.7)	31 (5.0)	23.81 (5.2)

*: significant difference between groups; +: significant difference among heights (p<.05)

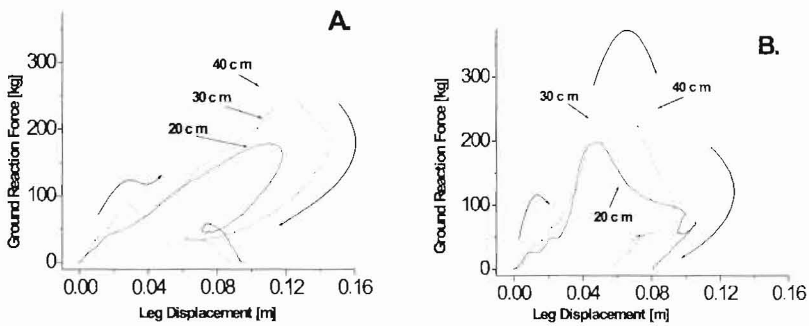

Figure 1. The relationship curves of Ground Reaction Force and Leg Displacement during downward stepping from different heights of a young (A) and an elder (B) subject.

Elder subjects compared to young subjects had no significant difference in maximal ground reaction force in landing from all heights. With the increase of landing height, the ground reaction force was increased significantly both for elder and young groups. The elders' maximal knee angular displacement was 12% less than the knee angular displacement in the young group (p<.05). With the increasing height , the angular displacement of the knee and the leg displacement were increased significantly for both the elder and young group. In agreement with other studies (Hortobagyi *et al*, 2000), present results revealed that elderly subjects stepped down with greater leg stiffness. Compared to young subjects, elder subjects had 13% greater leg stiffness generally for all heights (p<.05).

Dynamic Exercise CMJ- Table 2 shows the results of statistical analyses for CMJ: ground reaction force at the transition from eccentric to concentric contraction (Fi) and its index (Fi/BW), maximal knee angular displacement ($\Delta\theta_k$), c.m. vertical displacement (c.m. Disp), jump height (JumpH) and leg stiffness (Stif) for the elderly and young groups during CMJ.

Table 2. Mean values (with SD) and statistical analyses for selected parameters.

Group	Fi* [kg]	Fi/W*	$\Delta\theta_k$ * [deg]	c.m. Disp* [cm]	JumpH* [cm]	Stif* [kg/m]
Elder (n=10)	113.68 (18.87)	1.847 (0.237)	79.5 (11.5)	32.2 (8.4)	21.4 (4.5)	353.04 (80.23)
Young (n=10)	159.65 (4.42)	2.433 (0.215)	94.4 (6.8)	38.8 (5.3)	47.4 (7.6)	411.46 (52.86)

*: significant difference between groups; $p<.05$

The results reveal clearly that the elderly group has a significantly smaller range of motion and lower force index ($p<.05$) than the young group during CMJ. The leg stiffness during CMJ was significantly smaller for elderly too. Elder produced about 25% less ground reaction force index at the instant of transition from eccentric to concentric contraction and 42% less leg stiffness during CMJ. These results indicated that the ability of lower limb muscles to regulate the leg stiffness was less for elder people because of their weakness in producing force and limitation in range of motion. Summing up the results of downward stepping and CMJ, we can see that the leg stiffness during step down was independent from leg stiffness in a dynamic voluntary movement, i.e. CMJ. According to Houk (1979), stiffness is the dynamic interaction between the joint displacement and the force. In our opinion, the stiffness produced and adjusted by leg muscles during downward stepping is a motor response of neuromuscular system to the change of environment, namely the change of force, which was mainly produced passively during the landing. That means, the leg stiffness during step down is a passive production of neuromuscular system. It can therefore not reflect the ability of neuromuscular system to regulate stiffness.

CONCLUSION: The elderly group compared to the young group stepped down with a smaller joint range of motion and greater leg stiffness. The force and the leg stiffness during dynamic voluntary movement CMJ were significantly smaller for elderly. These results indicate that the leg stiffness over downward stepping is independent from dynamic leg stiffness during CMJ. With aging, the ability of neuromuscular system to regulate the leg stiffness for maximal dynamic voluntary contraction was significantly decreased.

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