RELATIONSHIP BETWEEN LOWER EXTREMITY STIFFNESS AND ECCENTRIC LEG STRENGTH IN HORIZONTAL JUMPERS

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KEY WORDS: stiffness, eccentric strength, jumping.

INTRODUCTION: Eccentric strength in the lower extremity has been identified as a key performance component in the horizontal jumps (Graham-Smith & Lees, 2005). Whilst isokinetic dynamometry provides a safe and reliable method of testing maximal eccentric strength, it is often criticised as being non functional due to testing at constant angular velocity and being an open kinetic chain movement (Baltzopoulos & Brodie, 1989; Augustsson & Thomeé, 2000). Therefore, eccentric leg strength measured during isokinetic testing may have limited transfer to functional performance. Lower extremity stiffness, such as vertical stiffness and knee joint stiffness (Farley et al., 1998) and knee joint moment, can be calculated during functional movements utilising force platforms, motion analysis and inverse dynamics. The purpose of this study was to examine the relationship between isokinetic eccentric leg strength and measures of lower extremity stiffness and knee joint moment during a single leg hop for distance test.

METHOD: Ten horizontal jumpers (7 male, 3 female) participated in the study. Prior to testing each athlete performed a thorough warm up consisting of 5 minutes cycling on an ergometer and 15 minutes of stretching. Concentric and eccentric peak gravity corrected torque of the quadriceps and hamstrings muscle groups were tested at 60 deg/s on a KinCom isokinetic dynamometer (Chattanooga Group, Inc., Hixson, TN) adopting the overlay method. Subjects were familiarised with the protocol and conducted warm up trials prior to data collection.
The two functional measures of lower extremity stiffness were determined via a hop and jump test on an AMTI (600400) force platform, whilst being tracked via a 10 camera Qualisys Pro Reflex and a Panasonic (NV-GS320) camcorder. Force data was sampled at 1200Hz and Qualisys captured motion at 240Hz. Subjects were required to hop from a 40cm high box onto the force platform positioned 1.5m away, and to jump as far as possible forwards. The distance jumped was determined via video analysis (Quintic 9.03, version 17) as the horizontal distance from the toe at take-off to the heel in the subsequent landing. Prior to performing the tests, each subject had cluster sets of 4 retro reflective markers placed on the thighs, shank and pelvis. The foot segment was defined by 4 markers placed on the calcaneous, 1st, 3rd and 5th metatarsals. Static markers placed on the medial and lateral malleoli, medial and lateral femoral condyles, greater trochanter, ASIS, PSIS and iliac crest were positioned to define the proximal and distal ends of each segment. Force and motion data were collected in QTrack (Qualisys AB) and exported as C3d files. Each athlete performed 3 trials on both legs.
Data was processed in Visual 3d (C-Motion, Inc., Rockville, MD, USA). A Butterworth 4th order zero lag filter was used to smooth the data adopting cut-off frequencies of 25Hz for motion and 15Hz for force. Joint moments were calculated using inverse dynamics via the link-model-base option. Knee joint stiffness was determined by the change in joint moment divided by the change in knee angle between the instants of touch-down and maximum knee flexion (Farley et al., 1998). Vertical stiffness was determined by the peak active force divided by the range of vertical displacement in the compression phase. Displacement of the centre of mass was calculated via double integration of the vertical acceleration graph. Average values of the 3 trials were taken.

RESULTS: Means (±SD) and Pearson's correlation coefficients between eccentric strength and stiffness measures for dominant and non dominant limbs are presented in Table 1.
Vertical stiffness was found to exhibit significant relationships with eccentric peak torque in hamstrings ($p<0.01$) and quadriceps ($p<0.05$) for dominant and non dominant legs. Knee joint stiffness was significantly related to eccentric peak torque in both quadriceps and hamstrings for the dominant leg, but not in the non-dominant leg. There was a significant

relationship between jump distance and eccentric peak torque of both the quadriceps and hamstrings for the dominant leg ($p<0.01$), and eccentric peak torque of the quadriceps in the non dominant leg ($p<0.05$).

DISCUSSION: Peak knee joint moments in the present study were slightly greater than the 250-300Nm range previously reported during the long jump take-off (Stefanyshyn & Nigg, 1998). However, these differences are likely to be due to the initial hop from a height of 40cm in the present study, placing a higher level of eccentric loading upon landing. In isolation peak knee joint moment was not significantly related to eccentric peak torque of the quadriceps or hamstrings. However, it is an integral variable in the measurement of knee joint stiffness and this was significantly related to eccentric strength of the quadriceps and hamstrings, but only for the dominant limb (both $p<0.01$). This highlights the importance of limiting the range knee flexion to enhance stiffness when jumping. Interestingly vertical stiffness yielded the strongest relationships to eccentric leg strength for both limbs. This may be due to the fact that vertical stiffness reflects the stiffness of the entire lower extremity, particularly around the knee and hip joints. It is recommended that future studies quantify stiffness around the ankle, knee and hip joints, and examine their individual and combined relationships with eccentric strength and performance.

Table 1. Relationships between eccentric leg strength and lower extremity stiffness

	Dominant				Non Dominant			
			Correlation (r)				Correlation (r)	
	Mean	± SD	Ecc Quads	Ecc Hams	Mean	± SD	Ecc Quads	Ecc Hams
Pk Torque Ecc Quads (Nm)	331	71	-	-	325	66	-	-
Pk Torque Ecc Hams (Nm)	163	37	-	-	171	51	-	-
Knee Moment (Nm)	408	162	0.473 NS	0.434 NS	368	124	0.466 NS	0.541 NS
Knee Stiffness (Nm/deg)	13.1	6.7	0.871**	0.736*	9.7	5.2	0.411 NS	0.451 NS
Vertical Stiffness (kN/m)	16.7	5.3	0.815**	0.855**	15.0	5.6	0.671*	0.900**
Jump Distance (m)	2.06	0.33	0.759**	0.832**	2.12	0.33	0.688*	0.493 NS

** $p<0.01$; * $p<0.05$; NS Non significant

CONCLUSION: Vertical stiffness measured in a hop test from a drop height of 40cm produced the highest association with eccentric strength of hamstrings and quadriceps. From an applied perspective, monitoring of vertical stiffness using a force platform could provide an indication of eccentric strength of the lower extremity relatively quickly and in a more functional way than isokinetic testing.

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