The Effects of Sex and Knee Support Level on Quasi-Stiffness of the Knee and Dynamic Stability during Landing

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Introduction

Dynamic joint stiffness has been defined as the slope of the line when joint moment is plotted against joint angle.[1] It has also been identified as "quasi-stiffness" of a joint and the linear portions of this curve can be interpreted as the resistance that muscles and soft tissue provide during joint motion.[2] Knee stiffness is inherently lower in women than men and this difference is thought to contribute to greater rates of knee injury during landing movements.[3] Knee support devices have been shown to influence the quasi-stiffness of the knee during the loading response of dynamic movements.[4] It is currently unclear how quasi-stiffness of the knee differs between men and women during landing and if both sexes respond similarly while performing with different levels of external knee support. The purpose of this study was to determine the influence of sex and varying levels of knee support on quasi-stiffness of the knee and dynamic stability during a landing task.

Methods

Five men (29.0 ± 3.3 y; 1.8 ± .1m; 83.0 ± 11.4 kg) and five women (26.9 ± 3.0 y; 1.7 ± .1 m; 72.1 ± 13.1 kg) without a history of traumatic knee injury participated in this study. Three, single leg hop and land trials from a horizontal distance, standardized to the participant's greater trochanter height, were performed with the dominant leg during 3 different levels of external knee support: none, moderate and high. The moderate level of knee support device consisted of a pair of tights with a built-in fabric banding system for knee support (Knee-Tec Tights, Opedix, Scottsdale, AZ) and the high level of knee support device consisted of a functional knee brace (Revolution, Top Shelf Orthopedics, Tracy, CA).

Fifty-four retro-reflective, spherical markers were placed on specific anatomical landmarks, captured with high speed video (100 Hz) and combined with the force plate data (1000 Hz) to calculate lower extremity, inverse kinematics and kinetics. Quasi-stiffness of the knee was calculated during the loading response from initial ground contact to peak knee flexion moment and was defined as the slope of the linear line of best fit when joint moment (Nm/kg) was plotted against joint angle (rad) (Figure 1). A larger positive slope indicates an increase in dynamic joint stiffness of the knee. Dynamic stability was calculated during the impact phase of the landing task (100 ms) from the deviations in the center of pressure on the support surface. The influence of sex and knee support level on the dynamic knee joint stiffness, knee range of motion (ROM), peak knee flexion moment, time to peak knee flexion moment, average velocity of the center of pressure (COP) path and the COP area were determined with a mixed-factor repeated measures ANOVA with one repeated measure (knee support level) using an alpha level of .05.

Results

A statistical sex by level of knee support interaction was found for quasi-stiffness of the knee ($p \leq .05$). A significant quadratic trend (U-shaped) was found for the effect of knee stiffness across the levels of knee support with a minimum at the moderate level of knee support condition (p=.023). Although the men performed similar to this trend across the levels of knee support, the women demonstrated progressively lower levels of knee stiffness as the level of knee support increased and on average demonstrated 25% less knee stiffness than the men.

The peak knee joint moment was influenced by sex and the level of knee support (both $p \leq .05$). Women demonstrated on average 20% lower peak knee joint moments during the landing task. A significant linear trend indicated progressively greater peak knee joint moments with progressively greater levels of knee support (p=.026) where the peak knee joint moments were significantly greater for the high versus moderate level of knee support (p=.019). A statistical sex by level of knee support interaction was found for the time to peak knee joint moment ($p \leq .05$). The women demonstrated a progressively longer time to the peak knee joint moment with progressively larger levels of knee support whereas the men demonstrated the opposite effects with shorter times to the peak knee joint moment as knee support level increased. Although no statistical main effects were found for knee ROM, a significant quadratic trend (inverted, U-shaped) was found for the amount of knee ROM used across knee support level with a maximum at the moderate level of knee support condition (p=.025) and women demonstrated on average 29% larger knee ROM during landing across the knee support conditions.

A statistical sex by level of knee support interaction was found for the COP average velocity ($p \leq .05$). The women demonstrated a progressively higher COP velocities with progressively larger levels of knee support whereas the men demonstrated the opposite effects with smaller COP velocities as support level increased. No statistical main effects were found for the COP area.

Discussion

Men and women responded with different quasi-stiffness values of the knee during landing across different levels of knee support. Progressively greater levels of knee support for women induced greater knee joint flexion ROM and lower knee flexion joint moments which reduced dynamic knee stiffness. Conversely, men responded with reduced knee flexion ROM and higher peak knee flexion moments with greater dynamic knee stiffness. These landing strategy differences translated into lower dynamic stability for women and higher dynamic stability for men. It is concluded that higher levels of knee support cannot be assumed to automatically produce higher levels of joint stiffness.

Significance

Dynamic knee joint stiffness cannot be presumed to be increased with higher levels of knee support during landing movements.

Acknowledgements

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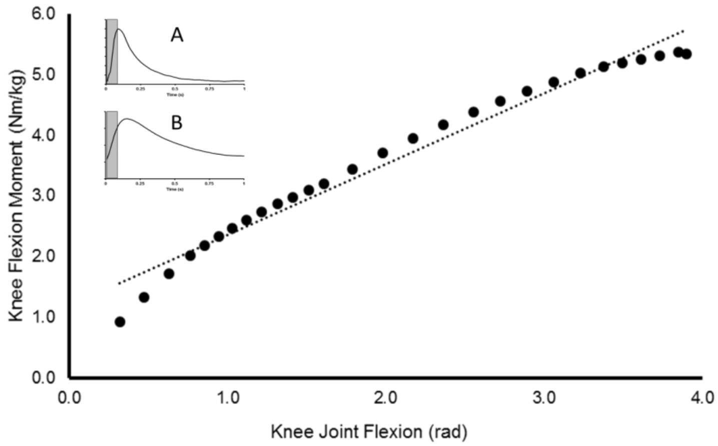

Figure 1. Dynamic knee joint stiffness ("quasi-stiffness") was calculated as the slope of the linear regression line (small dots) when the knee flexion moment (Nm/kg) is plotted as a function of knee joint flexion (rad). This was done during the loading response, represented by the shaded region on the knee flexion moment (A) and knee joint flexion plots (B).

Table 1. Means and standard errors (parentheses) for the dependent variables for men and women during the impact phase of single leg landings with three different levels of knee support: none, moderate, high.

	Men			**Women**		
	None	Moderate	High	None	Moderate	High
Knee Stiffness (Nm/rad)	6.1 (0.5)	5.5 (0.4)	7.9 (0.6)	5.0 (0.5)	4.9 (0.4)	4.8 (0.6)
Knee ROM (deg)	34.3 (4.4)	34.1 (3.3)	24.1 (3.8)	35.1 (4.4)	40.3 (3.3)	35.2 (3.8)
Peak Knee Flexion Moment (Nm/kg)	3.4 (0.8)	3.2 (0.3)	3.6 (0.2)	2.5 (0.2)	2.7 (0.3)	2.9 (0.2)
Time to Peak Knee Flexion Moment (msec)	104.0 (8.1)	94.0 (5.6)	86.0 (7.4)	88.0 (8.1)	104.0 (5.6)	108.0 (7.4)
Average Velocity of COP (cm/sec)	24.7 (19.1)	24.3 (15.5)	23.8 (21.2)	24.3 (19.1)	23.67 (15.4)	29.8 (21.2)
COP area (cm^2)	41.4 (6.7)	40.1 (7.8)	40.3 (5.3)	35.2 (6.7)	43.7 (7.8)	50.2 (5.3)

*ROM, range of motion; deg, degrees; msec, millisecond; cm, centimeter; COP, center of pressure