DYNAMIC ANGULAR STIFFNESS OF THE KNEE AND ANKLE DURING BAREFOOT AND SHOD RUNNING

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INTRODUCTION

Individual adaptation to changes in external conditions during running, such as surfaces and footwear, has been associated with adjustments in both leg stiffness settings and lower limb posture at initial ground contact (De Wit et al., 2000). The present study further examines this adaptation process by determining separate joint rather than whole leg stiffness adjustments during running barefoot and in two shod conditions. An accelerometry technique was employed to more accurately capture potential high frequency, non-linear aspects of the joint angle – joint moment relationship during the early stance phase.

REVIEW AND THEORY

Modelling the leg as a single mechanical spring, whole leg stiffness has generally been found to decrease when running on harder surfaces (Ferris et al., 1998), although De Wit et al. (2000) showed an increase in leg stiffness for barefoot versus shod running. This simplified approach however, combines any subtle adjustments made within the included joints. Stefanyshyn and Nigg (1998) provided a representation of single joint stiffness by examining the linear relationship between dynamic joint moment and joint angle at the ankle during the entire stance phase of running and sprinting. The purpose of this study was to evaluate adaptation to barefoot running using a similar joint stiffness estimate in order to further explain adjustment strategies. The linear relationship between joint moment and angle (or constant joint stiffness) was re-examined using transient movement characteristics often lost from lower limb joint kinetic measures (Wu, 1997).

PROCEDURES

Five healthy male subjects ran over a Kistler force platform, centred along a 30m runway, at a speed of 4.5m/s (±5%). All subjects completed trials running barefoot (BF) and wearing two different athletic shoes (S1 and S2). Sagittal plane angular kinematics were determined from a) displacement data recorded at 1000 Hz using a 3-camera ProReflex system and b) three-dimensional accelerations of the shank recorded at 2000Hz using two lightweight tri-axial accelerometers. The displacement and accelerometry data were filtered at 50Hz and 125Hz, respectively using a Butterworth digital low-pass filter. Ankle joint moments were calculated using the 1000 Hz displacement data, whilst the accelerometry data was used to more accurately describe the shank kinematics for knee moment calculations. Average joint stiffness during the first 50-ms (ankle) and 100-ms (knee) of stance was determined from the gradient of least square linear regression equations for the joint moment – joint angle curves (Stefanyshyn and Nigg, 1998).

RESULTS AND DISCUSSION

A universal decrease in knee joint stiffness and an increase in ankle joint stiffness were observed for all subjects when running barefoot compared to shod (Table 1). Generally, the magnitude of change in stiffness was comparable for both the knee and ankle, suggesting that whole leg stiffness may rely on a 'trade-off' between the two joints. Closer examination of the differences in knee and ankle stiffness for the two shod conditions rendered greater individual adaptation strategies. These findings indicate that it is unlikely that there is one prevailing joint that controls leg stiffness, contrary to the work of Arampatzis et al. (1999) where the knee was found to be primarily responsible for increasing leg stiffness at faster running speeds.

Table 1: Mean joint stiffness (Nm/deg) and peak joint moments (Nm).

	BF	**S1**	**S2**
Peak Impact Force (N)	1355 (264)	1681 (311)	1667 (496)
ANKLE			
Dorsi-flexor Moment (Nm)	-43.6 (27.7)	-22.3 (6.5)	-32.2 (15.5)
Plantar-flexor Moment (Nm)	199 (41)	184 (29)	171 (34)
Joint Stiffness (Nm/deg)	7.38 (2.24)	6.39 (2.36)	5.27 (1.08)
r^2 value	0.95 (0.03)	0.76 (0.23)	0.83 (0.11)
KNEE			
Flexor Moment (Nm)	-20.6 (9.4)	-25.5 (7.6)	-20.0 (13.4)
Extensor Moment (Nm)	275 (84)	297 (91)	306 (85)
Joint Stiffness (Nm/deg)	8.74 (2.73)	9.79 (3.26)	10.38 (2.98)
r^2 value	0.95 (0.04)	0.96 (0.04)	0.98 (0.02)

The addition of the true, high frequency transient kinematics from the accelerometry data was partly reflected by the elevated dorsi-flexor moments at the ankle. The r^2 values (Table 1) implied a linear relationship between the joint moments and angles, however, rapid oscillations in joint stiffness were also revealed, most noticable for the barefoot condition (Figure 1). Stefanyshyn and Nigg (1998) acknowledged this non-linearity of joint stiffness, but the additional high frequency characteristics present within this study have further substantiated their assumptions. Future work will aim to examine these oscillatory components with a view to better understanding the non-linear individual adaptations.

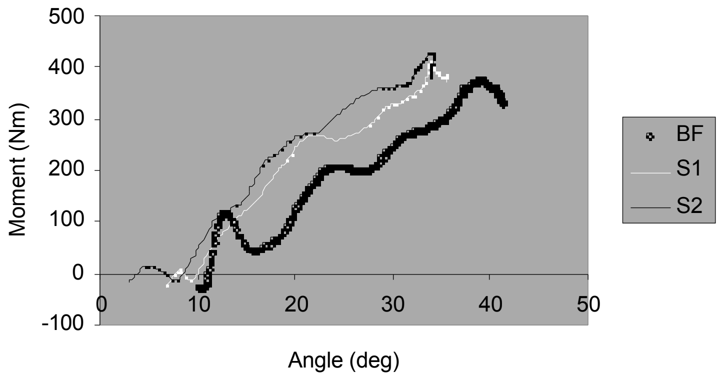

Figure 1: Joint angle – joint moment curves for the knee.

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