JOINT STIFFNESS IN OLD AND YOUNG RUNNERS DURING SHOD AND BAREFOOT RUNNING

Joseph Hamill[1,2,3], Julia Freedman Silvernail[1], Eric Rohr[4], Peter Brueggemann[5]

[1] Biomechanics Laboratory, University of Massachusetts, Amherst, MA, USA
[2] School of Sports, Health & Leisure, Republic Polytechnic, Singapore
[3] Dept. of Physical Education & Sports Sciences, University of Limerick, Ireland
[4] Human Performance Laboratory, Brooks Sports Inc., Bothell, WA, USA
[5] Institute of Biomechanics and Orthopaedics, German Sports University, Cologne, Germany

The purpose of this study was to investigate the relationship between ankle and knee joint stiffness in barefoot and shod running. Fifteen old and 15 young individuals served as participants in this study. Joint kinematics and kinetics were collected while the participants ran overground in two running conditions: barefoot and shod. A quasi-joint stiffness was calculated using the quotient of the change in moment divided by the change in angle for the ankle and knee joints. A two-way ANOVA was conducted to asses ankle and knee joint stiffnesses. There were no interactions and no main effects for the knee joint stiffness. For the ankle joint, there was only a significant difference between conditions. These results indicate that in barefoot running, it is necessary to have a more compliant ankle to maintain the heel from touching the ground.

KEY WORDS: running, joint stiffness, joint kinematics, joint kinetics, old, young.

INTRODUCTION: There is increasing interest in barefoot running as a means to reduce running injuries. It has been reported that loading rates and peak vertical impact forces are reduced in barefoot running compared to shod running (DeClercq et al., 1994; Dickinson et al., 1985; Komi et al., 1987). However, when individuals alter their footfall pattern from shod to barefoot, there appears to be a conscious change from a more natural heel-toe (RF) pattern to a midfoot (MF) or forefoot (FF) pattern. The difference in the latter patterns occurs when the heel contacts the ground after an initial ball-of-the-foot contact (MF) or the heel does not contact the ground (FF). In a recent study, Hamill et al. (2011a) reported that a significant majority of runners changed from an RF to a FF pattern when running barefoot on a firm surface. It has also been reported that older runners are more susceptible to running-related injuries than younger runners (Taunton et al., 2003).

One aspect of running that has not been investigated in the change from shod to barefoot running is joint stiffness. Increasing joint stiffness at the lower extremity joints during running has been implicated in running injuries (Hamill et al., 2011b). Further, a re-organization of the joint stiffness of the ankle and knee joints has been shown to occur when runners change from a RF to a FF pattern. Therefore, the aim of this study was to investigate joint stiffness in old and young individuals running in both barefoot and shod conditions. We hypothesized that there would be an alteration in knee and ankle joint stiffness in the shod and barefoot conditions. Second, we hypothesized that there would be greater joint stiffness in the old versus the young runners. Third, we hypothesized that the total stiffness would be greater in the shod versus the barefoot conditions.

METHODS: Thirty healthy individuals (15 old: 54.6±6.4 years, mass: 68.3±7.8 kg, height: 1.71±0.73m and 15 young: 21±2 years, mass: 68.6±7.9 kg, height: 1.72±0.67m) consented to participate in this study that was approved by the University ethics review committee. All were healthy and free of lower extremity injury at the time of data collection. In addition, all runners were classified prior to participation in this study as heel-toe or rearfoot runners.

Equipment: The experimental set-up consisted of a force platform (AMTI, Watertown, MA, USA) mounted flush with the floor in the center of a 25 m runway that was surrounded by an eight camera Qualysis Oqus motion capture system (Qualysis, Inc., Gothenburg, Sweden). Data sampling was accomplished for the kinematics and kinetics at 240 and 1200 Hz respectively. Both the force platform and motion capture systems were collected on the same microcomputer to ensure synchronization. Running speed was monitored by photoelectric sensors (Lafayette Instrument Company, Lafayette, IN, USA) placed 6 m apart.

Protocol: Upon approval for participation in the study, the participants then had retro-reflective markers placed on the right lower extremity in accordance with McClay & Manal (1999). The marker set consisted of 7 individual markers on the pelvis, two clusters of four markers (thigh and leg) and a three marker cluster on the rearfoot. Each participant was given sufficient time to practice in both barefoot (BF) and shod (SHOD) running conditions while running across the force platform at the required speed (3.5 m/s). In the shod condition, the participants wore a standardized running shoe provided by the laboratory that was considered a neutral shoe. Participants then completed five running trials in each condition. The order of conditions was randomized for each participant. No instructions on the footfall pattern were given in either condition.

Data Reduction: The kinematic and kinetic data were filtered with a Butterworth low-pass filter with a cut-off of 12 and 50 Hz respectively. Three-dimensional joint angles were calculated with respect to the proximal segment using a Cardan Xyz rotation sequence (flexion-extension, abduction-adduction and internal-external rotation) (Cole et al, 1993). A Newton-Euler inverse dynamics approach was used to calculate internal joint moments of the knee and ankle. While 3-D angles and moments were calculated, joint stiffness was calculated only in the sagittal plane. Joint stiffness was calculated for the shock attenuating phase (i.e. touchdown to midstance, see Figure 1) of the support phase by linearly fitting the slope of the moment-angle profile (Hamill et al., 2009):

$$\mathrm{stiffness} = \frac{\Delta\mathrm{moment}}{\Delta\mathrm{angle}}$$

This calculation does not truly represent the mechanical stiffness of the joint but can be considered “quasi-stiffness”.

Statistical analysis: The mean and standard deviation of the joint stiffness for both the knee and ankle joints were determined for each condition by averaging over all trials for all participants. The mean data of the shod and barefoot conditions were statistically analyzed using a two-way ANOVA (group X condition) for the ankle and knee joints with an alpha level of 0.5. A t-test was also used to test the difference between sum of the ankle and knee joint stiffness in the BF and SHOD conditions.

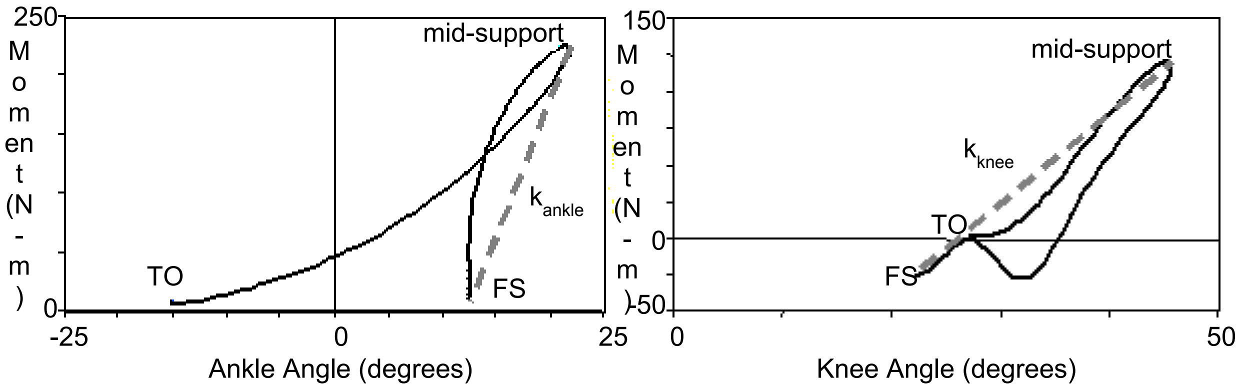

Figure 1. Calculation of ankle joint stiffness (left) and knee joint stiffness (right). Stiffness was determined as the absolute value of the linear slope of the dashed line from touchdown (FS) to mid-stance of the support period.

RESULTS: While no instructions were given regarding the type of footfall pattern to be used in the barefoot condition, 12 of the older and 10 of the younger participants altered their footfall pattern from RF to FF. Hence, the analysis on the BF condition only includes those that changed to an FF pattern and their corresponding SHOD condition. The mean ankle and knee joint stiffness values for both conditions are presented in Figure 2.

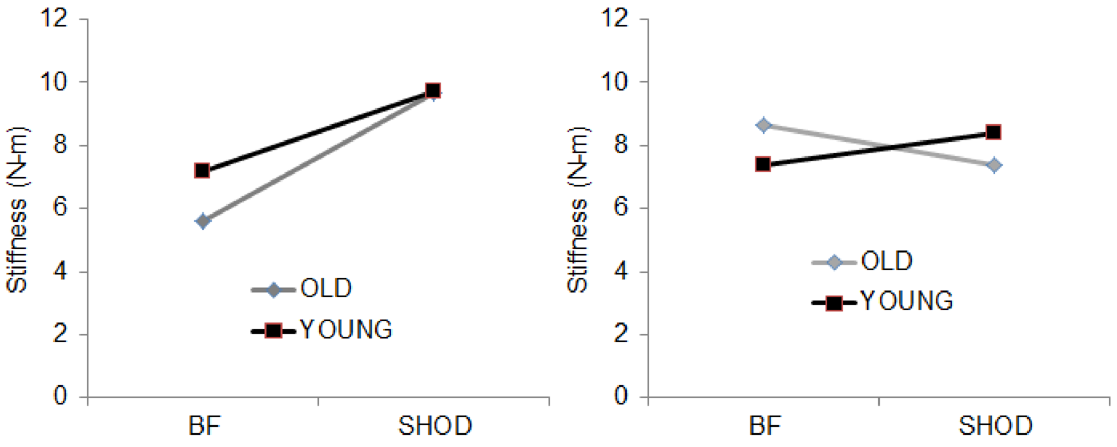

Figure 2. Mean (±) joint stiffness values across all subjects for the ankle (left) and knee (right) joints in the barefoot and shod conditions.

For the analysis on the ankle joint stiffness, there was no significant group X condition interaction nor group main effect ($p > 0.05$). However, there was a significant difference between the BF and SHOD conditions ($p < 0.05$). For the knee joint, there were no significant differences for the interaction or the main effects ($p > 0.05$). There was a significant difference between the BF and SHOD conditions ($p < 0.05$) with the SHOD condition exhibiting a greater total stiffness (i.e. sum of ankle and knee stiffness) than the BF condition (35.18 v. 28.79 N-m).

DISCUSSION: The aim of this study was to investigate joint stiffness in old and young individuals running in both barefoot and shod conditions. We hypothesized that there would be a difference in the ankle and knee joint stiffness in the BF and SHOD conditions. This hypothesis was partially supported in that there was a change in the ankle joint stiffness but no change in the knee joint stiffness between conditions. The change in the ankle stiffness was expected because, to inhibit the heel from contacting the ground, the ankle joint must have a degree of compliance. It was not expected that the knee stiffness would remain the same. For the second hypothesis, we suggested that there would be greater joint stiffness in the old versus the young runners. This hypothesis was not supported. The difference in groups was not evident because all of the runners in the two groups in this study were matched for mileage and all ran at the same speed. The third hypothesis that the total stiffness would be greater in the SHOD versus the BF condition was supported. In the BF condition, with no shoe to attenuate the impact, primarily the ankle and secondarily the knee joint acted together to attenuate the impact shock. In the SHOD condition, it was not necessary for these joint to be compliant because the shoe could act to attenuate some of the impact shock.

CONCLUSION: There is a difference in the ankle joint stiffness between BF and SHOD running with BF running resulting in greater ankle compliance. Since there was no difference in knee stiffness between BF and SHOD, the total ankle and knee stiffness was dominated by the ankle and was different between BF and SHOD running. The total stiffness compliance in BF running is necessary to attenuate the impact shock while in SHOD running the addition of the shoe allows for greater total stiffness.

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