THE EFFECT OF RUNNING-INDUCED NEUROMUSCULAR FATIGUE ON LEG STIFFNESS

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INTRODUCTION

Between 27% and 70% of runners endure overuse injuries during any one-year period, leading to significant time lost from physical activity, mental and emotional stress, and substantial medical costs [1]. Prevention of these injuries is critical to long-term health, but factors leading to injury appear complex and variable. Neuromuscular fatigue has been linked to running-related injury, potentially due to a loss of coordination, decreased force production, and alterations in muscle activation patterns [2]. Additionally, lower extremity stiffness may be a factor influencing the development of running-related injuries. A runner’s mechanical stiffness has been suggested to tune optimally to enable efficient utilization of stored elastic energy while preventing high loading rates associated with bony stress injuries [3]. Lower-extremity mechanical stiffness during running is typically measured by leg stiffness, which is the ratio of maximal vertical ground reaction force (VGRF) to maximal leg compression during stance [4].

Mechanical stiffness and fatigue are likely correlated, as fatigue-induced decreases in force production and/or increases in contact time would reduce stiffness. Ostensibly, runners who exhibit the largest changes in stiffness due to fatigue may also be at highest risk for running-related injuries. The extent to which fatigue influences stiffness, however, is not well known. Therefore, the purpose of this investigation was to analyze changes in mechanical stiffness of the lower extremity over the course of a run to exhaustion.

METHODS

Twenty-eight experienced, rearfoot-striking runners (14 males, 14 females; age: 34.6 ± 7.4 yr; mass: 71.3 ± 10.1 kg) were recruited. Subjects completed one time-to-exhaustion (TE) running trial on an instrumented treadmill (h/p/cosmos, Zebris Medical, Germany). Subjects completed a 10-minute warm-up run at 70% VO$_{2}\text{max}$ speed and then immediately transitioned into a constant-speed TE run at 85% VO$_{2}\text{max}$ speed. Subjects continued running until they terminated the run or reported 18 out of 20 on the Borg 20-point Perceived Exertion scale, whichever occurred first.

Lower-body and trunk kinematical data were measured with wireless inertial measurement units (IMU; 200 Hz; MyoMotion, Noraxon USA) consisting of miniature IMU sensors attached to the feet, shanks, thighs, pelvis, and upper thorax. Sensors were carefully secured with flexible adhesive tape. A subject-specific neutral-posture calibration was conducted prior to commencing running. Native algorithms integrated the calibration and IMU data to report three-dimensional segment orientations and joint angles.

Pressure data (100 Hz) was collected from the treadmill and used to calculate vertical ground reaction force (VGRF), ground contact time (CT), and stride rate (SR). Rate of perceived exertion (scale: 6-20) was recorded every 5 minutes. Respiratory exchange ratio, oxygen consumption, and heart rate were measured by a breath-by-breath gas analyzer (K4b2, Cosmed USA) and chest strap (Polar USA) and monitored as secondary indicators for the TE trial.

For each stance phase, leg stiffness was estimated from treadmill speed, subject height, VGRF, and CT using the sine-wave method [4]. Additionally, foot strike angle (FSA) was determined as the pitch angle of the foot segment relative to neutral posture (flat foot) at the instant of footstrike, as determined by VGRF > 5N. Values for each metric were averaged over 30 stances at 0%, 50%, and 100% of
the running trial. Repeated-measures ANOVAs with Bonferroni correction for multiple comparisons were performed in SPSS to determine the effects of time and sex on each outcome variable. The statistically significant level was set at 0.05.

RESULTS AND DISCUSSION

On average, time to exhaustion was 31.3 ± 9.1 minutes. For leg stiffness, there was no significant main effect of time, F(2,26) = 1.85 (p = 0.168). There was a significant main effect of sex for leg stiffness, F(2,26) = 30.31 (p < 0.001), primarily due to differences in body mass. Interestingly, a significant time-by-sex interaction for leg stiffness was detected, F(2,26) = 6.78 (p < 0.005). Male leg stiffness increased on average from 6.78 ± 0.99 kN/m at 0% to 6.93 ± 1.06 kN/m at 50% to 7.13 ± 1.08 kN/m at 100%. In contrast, female leg stiffness decreased slightly over the trial from 5.02 ± 1.00 kN/m at the start to 4.91 ± 0.84 kN/m at the end.

For FSA, there was a significant main effect of time, F(2,26) = 7.89 (p < 0.005). There was no significant main effect of sex, F(2,26) = 0.05 (p = 0.829), and no significant time-by-sex interaction, F(2,26) = 0.68 (p = 0.511). FSA decreased from start (13.30 ± 5.13°) to end (11.34 ± 5.56°) of the TE trial for both males and females.

Previous studies of the effect of running-induced fatigue on leg stiffness reported significant decreases in leg stiffness [5,6]. These studies, however, did not examine sex-specific responses. Differences in methodology, including running velocity and the duration of the time trial, may account for some inconsistencies between the present study and previous work. Additionally, both aforementioned studies analyzed younger subject populations (age: 28.3 and 16.9 yr), which may respond to running-induced fatigue differently than the slightly older population of the current study.

Decreased FSA indicates a progressively flatter foot posture at initial contact with fatigue, which may account for some of the changes in leg stiffness. However, the disparate response for males and females despite similar decreases in FSA suggests other sex-specific factors are likely involved.

CONCLUSIONS

Results of the current study have important implications for understanding gender-specific responses of lower-extremity stiffness to running-induced fatigue. Findings suggest that the mechanisms of running-related injury in males and females may be different, and future research methods should account for potential sex disparities.

REFERENCES


ACKNOWLEDGEMENTS

The authors thank adidas AG for supporting this research.