Sex-specific changes in movement dynamics of whole-body motion during fatigued running

Yiyang Chen[1,2], **Jill Emmerzaal**[1], Caroline Paquette[1,2], Julie N. Côté[1,2], Philippe C. Dixon[1]
[1]Department of Kinesiology and Physical Activity, McGill University, Montreal, Canada
[2]Jewish Rehabilitation Hospital Site of CISSS-Laval and Research Site of the Montreal Centre for Interdisciplinary Research in Rehabilitation, Laval, Canada
Email: Yiyang.chen3@mail.mcgill.ca

Summary

This study explores how fatigue affects movement patterns in male and female endurance-trained runners. We placed an inertial measurement unit (IMU) sensor on the lower-back to estimate whole-body motion before and after a fatiguing run. Fatigue led to decreased step and stride regularity and increased entropy of trunk accelerations. Males showed increased variability in movement with fatigue, while females exhibited a more rigid movement pattern. These findings highlight sex differences in running biomechanics, revealing the importance of applying sex-specific metrics, such as movement smoothness (Log Dimensionless Jerk), into fatigue monitoring and training approaches in endurance runners.

Introduction

Wearable lower back accelerometers have been widely used to analyze whole-body aspects of locomotion in sports and locomotion in general [1]. Linear and non-linear measures of trunk accelerometry have been used to infer fatigue-specific deviations of center of mass in running [2]. It remains unknown whether the running-induced fatigue, as measured with lower back accelerometry, would be similar between sexes. This study aimed to determine 1) the effects of fatigue on movement dynamics of lower back accelerometry in endurance-trained runners and 2) if males and females would show similar movement dynamics with fatigue.

Methods

Thirty-two endurance-trained runners (16 females; weekly distance: females: 59 ± 26 km; males: 68 ± 30 km) performed a fatiguing running task until volitional exhaustion of 20 on a Borg CR20 scale. An IMU placed on the pelvis/lower-back (Lumbar vertebrae 4–5; APDM, Inc., Portland) recorded a 40-second running bout at 10 km/h before and after the fatiguing run. Raw acceleration signals in vertical (VT), mediolateral (ML) and anterior-posterior (AP) directions were used to analyze movement dynamics. Step and stride regularity (unbiased autocorrelation), linear variability (absolute and ratio root mean square; RMS), complexity (Sample Entropy), smoothness (Log Dimensionless Jerk; LDLJ), and stability (short- and long-term Lyapunov Exponent) were calculated. Generalized estimating equations were used to assess the sex and fatigue effects and their interactions on each measure.

Results and Discussion

For step and stride regularity, there were significant interaction effects on ML stride regularity (p=0.019), with males showing a decrease after fatigue. There were significant fatigue main effects on AP stride and step regularity (p<0.001), showing a decreased regularity after fatigue. The less regular accelerations may indicate asymmetrical braking and propulsive phases between strides and steps with fatigue [2], with males showing asymmetrical patterns in ML direction. No differences were found in females.

For linear variability, there were significant interaction effects on VT (p=0.007) and ML absolute RMS (p=0.037), with males showing an increase in both VT and ML after fatigue. There were fatigue main effects on VT and ML RMS ratio (p<0.001), showing a decrease in VT direction and an increase in ML direction. There were main effects of sex on VT (p=0.045) and AP RMS ratio (p=0.043), with females showing a lower VT RMS ratio and a higher AP RMS ratio compared to males.

For movement complexity, there were fatigue main effects on VT and AP Sample Entropy (p<0.001), showing an increase in VT and AP Sample Entropy after fatigue. The more complex and less predictable VT and AP accelerations may indicate healthy and protective control strategies in endurance runners with fatigue [3].

For movement smoothness, there were significant sex main effects on LDLJ (p=0.045). A significantly lower LDLJ was found in females compared to males, indicating females may have a more rigid acceleration pattern, which may reduce their force attenuation capabilities and help explain their higher risks to injuries.

Conclusions

Endurance-trained runners may use a less regular and less predictable whole-body motion with fatigue. Male runners may use a variable control strategy with fatigue, while female runners may use a rigid control strategy regardless of fatigue.

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