Soft Tissue Motion Increasingly Impacts the Calculation of Lower Limb Inertial Parameters as Running Speed Increases

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Summary

Soft tissue motion influences the inertial parameters of the lower extremity during landing [4]. Lower limb soft tissue was analysed in seven athletes at four different running speeds using marker arrays and Delaunay triangulation. Transverse moments of inertia in the lower extremity during ground contact oscillate with a range of approximately 10% of static values for the shank and were influenced by speed.

Introduction

Mechanical analysis at the whole human body level typically assumes limbs are rigid bodies with fixed inertial parameters [1]. However, most of the thigh and shank segments are not rigid, (thigh soft tissue is 90.3% and shank is 77.7% of the total segment mass [2]). Consequently, soft tissue motion influences the inertial parameters of the lower extremity as demonstrated in [3]. Similar changes during running could be expected but little is currently known. The present research aims to quantify the changes in inertial parameters due to soft tissue motion when running at different speeds. It was hypothesized that as speed increases inertial changes will increase and be detectable by the methods presented in [3].

Methods

Seven athletes (age: 24 ± 4.2 years, height: 1.77 ± 0.08 m, mass: 79.56 ± 10.5 kg) gave informed consent and had the soft tissue motion of the shank and thigh quantified in 3D by 8x9 arrays of 6.4 mm reflective markers (details in [3]). These were recorded at 750 Hz and gap filled using automatic motion capture (Vicon Nexus 2.14, Oxford, UK) at four speeds. One trial per person per speed was analysed for one ground contact (GC) phase. Data were filtered at 100 Hz using a low pass, fourth order, zero lag, Butterworth filter. A Delaunay triangulation of marker positions divided the thigh and shank segments into multiple tetrahedra, to obtain soft tissue mass, volume, and centre of mass (COM). The inertia tensor was derived about this COM, and the parallel axis theorem was used to obtain the inertia tensor about the rigid body COM (I_0), determined from inverse kinematics of joint markers on the athletes and DeLeva [4].

Results and Discussion

For each speed, soft tissue oscillation was evident for the first 60% of GC for both segments (Figure 1). The shank had a larger percentage change in I_0 upon GC at both speeds. Both lower limb segments had the most variation and oscillation at 20 km.h^{-1} compared to 11 km.h^{-1}. The pattern of oscillation was similar between athletes and changed in a comparable manner with speed.

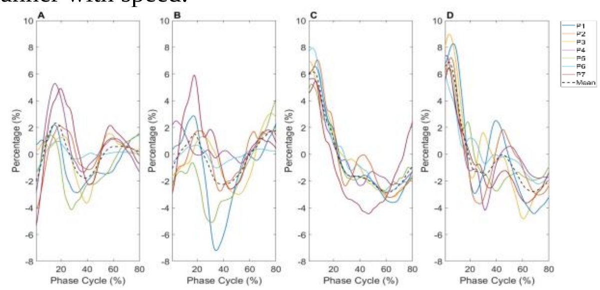

Figure 1: Percentage change for transverse I_0 (Ixx) about the rigid COM in the thigh (A-B) and shank (C-D) for 11 km.h^{-1} (A and C) and 20 km.h^{-1} (B and D).

The shank had a greater percentage range in I_0 compared to the thigh which steadily increased with speed (Table 1). However, the percentage range of the thigh did not steadily increase with speed. There was a large standard deviation at 14 km.h^{-1} for the thigh and it is unclear if this was due to a change in technique between lower and higher speed running for some of the athletes. The low number of subjects limited statistical analysis.

Conclusions

Inertial parameters of the thigh and shank were found to change during GC as running speed increased. Findings demonstrate that faster running speeds have a greater range of percentage change in I_0, with the shank having a greater range compared to the thigh.

References

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Table 1: Maximum and minimum transverse I_0 and percentage change ranges for 11, 14,17, and 20 km.h^{-1}. Mean ± standard deviation.

Running speed (km.h^{-1})	Max Ixx (kg.m^2)		Min Ixx (kg.m^2)		Range Ixx (%)	
	Thigh	Shank	Thigh	Shank	Thigh	Shank
11	5.15e^{-2} ± 9.10e^{-3}	2.29e^{-2} ± 5.62e^{-3}	4.74e^{-2} ± 8.72e^{-3}	2.07e^{-2} ± 4.98e^{-3}	8.90 ± 2.61	10.62 ± 1.29
14	5.21e^{-2} ± 9.87e^{-3}	2.23e^{-2} ± 5.82e^{-3}	4.71e^{-2} ± 8.27e^{-3}	2.07e^{-2} ± 5.04e^{-3}	10.64 ± 6.68	10.72 ± 2.19
17	5.14e^{-2} ± 9.50e^{-3}	2.31e^{-2} ± 5.86e^{-3}	4.67e^{-2} ± 8.14e^{-3}	2.06e^{-2} ± 5.04e^{-3}	9.80 ± 3.66	11.98 ± 2.01
20	5.11e^{-2} ± 1.04e^{-2}	2.32e^{-2} ± 5.75e^{-3}	4.66e^{-2} ± 8.77e^{-3}	2.08e^{-2} ± 5.27e^{-3}	9.51 ± 3.52	12.05 ± 1.97