Inaccurate estimation of center of mass state from kinematics during human running

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1 Summary

Stability analyses of running are based on an analysis of the trajectory of the whole-body center of mass (CoM). This cannot be directly measured, but is typically inferred from kinematic markers placed on the body. This study shows evaluates the accuracy of three such kinematic models of the CoM during the flight phase of human running. The state-of-the-art model requiring 38 markers placed on the full which has a mean acceleration error of 2.4 m/s^2. This error is even larger (4.8 m/s^2) when the CoM position is estimated from hip markers alone. This limited accuracy may compromise stability analyses. Accuracy may be improved by combining kinematic and force plate recordings.

2 Introduction

The stability of running in humans, other animals and robots can be assessed from the step-to-step variability of the trajectory of the CoM. Rather than considering the full trajectory, stability analyses typically focus on the state of the CoM at successive flight apexes. This state is characterized by the CoM height, forwards speed and lateral speed. The position of the CoM cannot be directly measured and is instead estimated using kinematic markers placed on the body. A common approach is to place 1 to 4 markers on the hips and use the hip midpoint as a proxy for the CoM. A more advanced approach is to use a kinematic model [1], [2]. In this case, the body is divided into segments and a model is used to determine the weight and CoM of each segment, which are then combined to obtain the whole body CoM. The state-of-the-art kinematic model requires measuring the position of 38 markers [1], which is cumbersome and time consuming. Therefore, simplified versions of this model have been proposed [2]. This study compares the accuracy of these kinematic estimates of the CoM position during human running.

3 Methods

Data from a publicly available database were analyzed [3]. Two subjects performed treadmill running for one minute at 3 m/s and 4 m/s. Marker positions were smoothened to obtain smooth marker accelerations [4]. These were then used to calculate the CoM position according to three kinematic models: 1. the state-of-the-art model, requiring 38 markers [1], 2. a simplified version requiring 13 markers [2], 3. the hip mid-point, requiring 4 markers. The CoM position was differentiated twice to obtain acceleration. Only the flight phases of running were analyzed.

4 Results

During the flight phase of running, the acceleration of the CoM is equal to gravity, i.e. null in the horizontal plane and downwards of amplitude 9.81 m/s^2. However, the mean acceleration calculated from all three kinematic models had a bias both in the vertical direction and in the horizontal plane.

Downwards acceleration was overestimated by 1.2 m/s^2 for both the simplified and hip models, and by 0.7 m/s^2 for the full model. This means that the vertical oscillations of the hip markers and of the simplified model (and, to a lesser extent, of the full model) during flight are larger than the actual vertical oscillations of the CoM. This leads to a systematic overestimation of the height of the CoM at apex.

In the horizontal plane, the CoM acceleration during flight is null. The hip markers however had a systematic backwards acceleration (slowing down throughout the flight phase) of 3.0 m/s^2 on average. The simplified and full models had a systematic forwards acceleration of 0.8 and 0.3 m/s^2 respectively. Additionally, the hip markers had a systematic lateral acceleration. During the flight phase between taking off with right foot and landing with the left foot, the CoM has a constant leftwards velocity. The leftwards velocity of the hip markers however increases during flight, with an average acceleration of 1.2 m/s^2.

Altogether the mean error in acceleration was largest for the hip markers (4.8 m/s^2), followed by the simplified model (3.7 m/s^2) and the full model (2.4 m/s^2).

5 Conclusions

During flight, the CoM follows a parabolic trajectory with constant downwards acceleration equal to gravity. This is however not the case for all three tested kinematic CoM models during the flight phase of running. The acceleration error is largest for the hip markers followed by the simplified then the full model. This results in a systematic overestimation of the amplitude of the vertical CoM oscillations during flight and an inaccurate estimation of the CoM speed. Stability analyses of running require accurate estimations of CoM height and horizontal speed during flight, and are therefore limited by the inaccurate estimation of CoM state. Accuracy may be improved by combining kinematic and force plate recordings.

References

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