Measuring the functional base of support of the human foot

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Summary

Many older adults suffer injuries due to falling. Some of these injuries could be prevented if it were possible to assess dynamic balance accurately. One way to assess dynamic balance is to analyze the margin-of-stability (MOS): the shortest distance between a person's base-of-support (BOS) and a model-based point of balance. The BOS is often represented using a single motion capture marker, which is a poor approximation of the BOS. In this work, we compare two more detailed BOS models: a marker-based model that approximates the anatomical outline of the foot, and a functional BOS (fBOS) model. Our fBOS model is defined as the area of the foot's sole that can support at least 40% of the body's weight. Our analysis shows that the fBOS is only a quarter of the size of a marker-based BOS, making it essential to use the fBOS to obtain an accurate value for the MOS.

Introduction

Balance is a complex whole-body skill that is difficult to analyze without a model. Dynamic models of balance [1, 2] use the body's kinematics to calculate the MOS: the distance between the BOS and a point of balance on the ground. In this work, we assess the accuracy of two detailed BOS models in barefoot and running shoe conditions: a marker-based BOS model, and the fBOS model.

Methods

Twenty-eight young adults (28 ± 6yr, 11 females, $23 \pm 3\text{kg/m}^2$, 28 barefoot, 26 shod) participated in the experiment. The motions of the participant's feet were recorded using a Qualisys motion capture system and a 6-marker layout (Figre 1B) while ground forces under each foot were recorded using two Bertec force plates. To experimentally measure the fBOS, we instructed participants to move their COP in large circles while keeping the bottom of their feet in contact with ground (Figure 1A). Using a quiet standing trial, we computed the location of the foot sole plane and the transformations needed to locate this plane using the foot markers. The fBOS of each trial is calculated by first removing COP points that have less than 40% of body weight, next by projecting the remaining points onto the foot sole plane, and finally by computing the convex hull of the projected points (Figure 1B). Using a Wilcoxon rank sum test, we compare the area (Figure 1C) enclosed by the fBOS (A_F) with the marker area (A_M), and the area of the fBOS during barefoot and running shoe conditions.

Results and Discussion

The average area of the fBOS is one quarter of the average area enclosed by the IOR markers (Figure 1D), while there is no difference between the barefoot and shod conditions fBOS (Figure 1E). While there was considerable variation in the relative area of the fBOS ($5\% - 38\%$) the size of the fBOS was not different between barefoot and shod conditions.

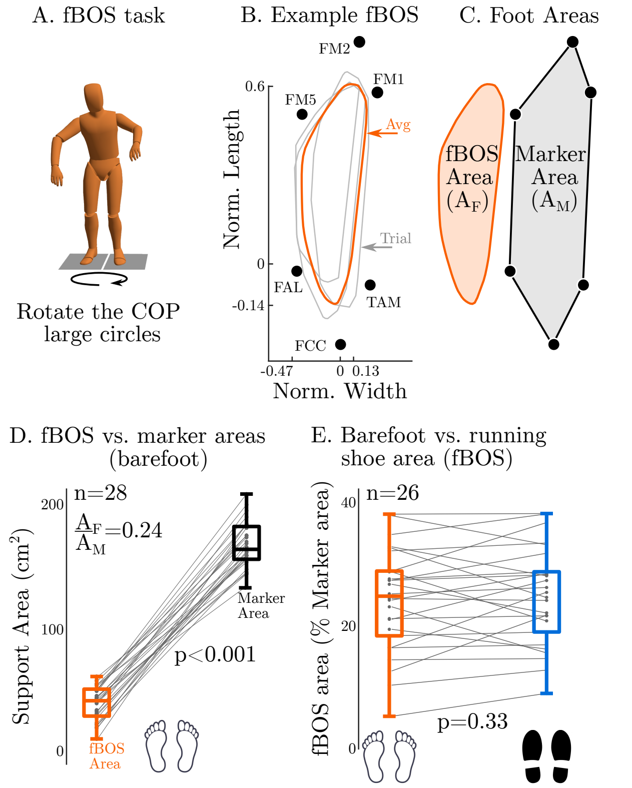

Figure 1: We recorded foot motions and ground forces as participants rotate their COP as widely as possible (A.). We processed the kinematic and force data to yield fBOS profiles for each trial and evaluated an average fBOS profile for each participant (B.). The fBOS area A_F (C.) is much smaller (D.) than the area enclosed by the foot markers A_M. In contrast, the area of the fBOS is the same whether barefoot or with running shoes.

Conclusions

The fBOS area is far smaller the marker-based BOS model and is similar between barefoot/running shoe conditions. The accuracy of any MOS analysis will be improved by using the fBOS rather than a marker-based BOS model.

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