Ground Reaction Forces during Running can be Estimated from Insole Pressure Measurements by Considering Whole Body Dynamics

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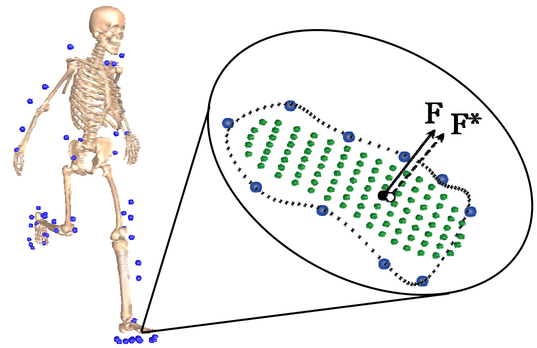
INTRODUCTION

Insole pressure sensors allow one to gauge the pressure distribution on the foot, in addition to the net center of pressure (COP) and vertical force (Chesnin et al. 2000). However, current insoles do not provide measures of shear force, which means that traditional biomechanical analyses of joint and muscle loads cannot be conducted. Kuo (1998) showed that center of pressure information may be sufficient to estimate shear forces when a least squares inverse dynamics (LSID) approach is used. We have extended these ideas to generate least squares forward dynamic (LSFD) simulations of locomotion that are dynamically consistent over time (Remy et al. 2008). The objective of this study was to evaluate the accuracy of using insole pressure data together with LSFD to estimate ground reactions during running.

METHODS

Five healthy young adults (25 ±2 yrs, 68.9 ±6.8 kg, 172 ±5 cm) were tested. Ground reactions (1000 Hz) were recorded while each subject ran at two speeds (preferred, fast) over a fixed force plate (AMTI), with three repeated trials performed for each speed. Pressure sensitive insoles (99 capacitive sensors per insole, Novel Inc.) were used to record the pressure distribution (100 Hz) on the bottom of the feet during all trials. Whole body kinematics (200 Hz) were simultaneously recorded using a motion capture system (Fig. 1a).



(a) (b)

Figure 1: a) Whole body kinematics. b) LSFD estimates of the ground reaction force, **F***, were compared with forceplate measures, **F**.

Ten markers located around the periphery of the shoe were used to track the insole sensor positions. At each frame, a natural cubic spline through the 10 markers was used to infer the positions of 100 virtual markers around the shoe (Fig. 1b). Each subject performed a standing static calibration trial in which he/she stood one-legged on a forceplate while voluntarily shifting the center of pressure. This data was used to determine a linear transformation from the ground to the insole reference frame that minimized differences between the insole and forceplate COP trajectories. During running trials, piecewise affine transformations applied to the 100 virtual markers were then used to determine the position of each insole sensor. Sensor positions and pressure measurements were subsequently used to estimate the center of pressure and net vertical force on each foot (Chumanov et al. 2007).

We used then LSFD to estimate the ground reactions through the stance phase of running. At each time step, a least squares solution of the equations of motion of a 27 degree of freedom whole body model was performed. Specifically, we solved for joint accelerations and ground reactions that acted at the insole center of pressure, while minimizing the discrepancy between estimated and measured accelerations. Estimated accelerations were then numerically integrated to obtain the resulting joint velocities and positions. Optimization was employed to determine a set of initial velocities and positions that produced a forward simulation that was consistent with measured marker kinematics (Remy et al. 2008)

RESULTS

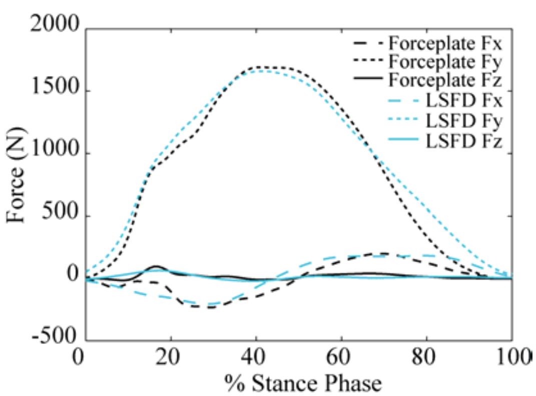


Figure 2: LSFD estimates of the ground reactions derived from the insole pressure data agree well with forceplate measures

The insole sensor tracking algorithm generated COP trajectories that were within 10 mm of forceplate measures for all trials.

Root mean square (RMS) errors in the estimated shear forces averaged from 5-8 N in the medio-lateral direction and from 10-15 N in the anterior-posterior directions (Table 1). These errors are less than 8% of the peak force measured in these directions (Fig. 2). The largest error in shear force estimates tended to occurr at heel contact and toe-off, which may results from deviations in the insole COP position at those portions of stance.

DISCUSSION

We have demonstrated that least squares forward dynamics can be used together with insole pressure data to obtain reasonably accurate estimates of ground reactions during running. This advance could facilitate the use of insoles to analyze joint and muscle mechanics during running on un-instrumented surfaces or treadmills.

REFERENCES

Chesnin, KJ, et al. (2000). *Gait Posture* 12, 128-133.

Chumanov, et.al. (2007). Conference abstract, *Am Society of Biomech*, Stanford, CA.

Kuo, AD. (1998). *J Biomech Eng* 120, 148-159.

Remy, CD, et al. (2008). *J Biomech Eng*, in press.

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Table 1. RMS errors (mean (sd)) for measured COP and estimated forces.

	COPx (mm)	COPz (mm)	A-P (Fx, N)	Vertical (Fy, N)	M-L (Fz, N)
Preferred Run	8.2 (4.9)	4.6 (1.2)	10.4 (7.2)	15.6 (7.1)	5.0 (1.8)
Fast Run	5.5 (1.1)	1.8 (1.0)	15.3 (7.2)	22.8 (5.6)	8.4 (3.2)