Tracking the Position of Insole Pressure Sensors during Walking and Running

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INTRODUCTION

Pressure sensitive insoles have emerged as a powerful tool for assessing the pressure distribution on the sole of a foot. The pressures measured by the insole sensors can also be combined to determine a partial set of net ground reactions (COP-center of pressure, vGRF - vertical ground reaction force) (Barnett, *et.al*, 2000, Chesnin, *et.al*, 2000). Such information could conceivably be used within a least-squares inverse dynamics approach (Kuo, 1998) to estimate joint kinetics, thereby providing an alternative to fixed forceplates. However, using insoles for inverse dynamics analysis would require the global position of the insole sensors be tracked with high fidelity. This is a challenging requirement to achieve since the flexible insoles are embedded in a shoe which can undergo large motion and deformations. The objective of this study was to develop and evaluate the use of an array of motion capture markers affixed to a shoe to track insole sensor positions during walking and running. The accuracy of the approach was assessed by comparing the estimated position of the COP and the net vGRF with values measured using a fixed forceplate.

Figure 1. Ten markers (15 mm) affixed around the periphery of a running shoe were used to track insole sensor positions.

METHODS

Five healthy young adults (25 ±2 yrs, 68.9 ± 6.8 kg, 172.5 ±5.5 cm) were tested. Each subject walked at three speeds (slow, preferred, fast) and ran at two speeds (preferred, fast) over a fixed forceplate (AMTI). Three repeated trials at each speed were performed. Each subject also performed a standing static calibration trial, in which he/she stood on a fixed forceplate while voluntarily shifting the center of pressure in the anterior-posterior and medio-lateral directions.

A motion capture system (Motion Analysis) was used to measure the kinematics of ten markers affixed to the periphery of a pair of running shoes (Figure 1). Pressure sensitive insoles (99 capacitive sensors per insole, Novel Inc.) were fitted into the shoes to measure the pressure on the bottom of the feet for all trials. Pressure data was acquired at 100Hz synchronously with the kinematic (200Hz) and forceplate data (2000Hz). At each frame, we used a natural cubic spline through the positions of the 10 motion capture markers to infer the positions of 100 virtual markers around the periphery of the shoe.

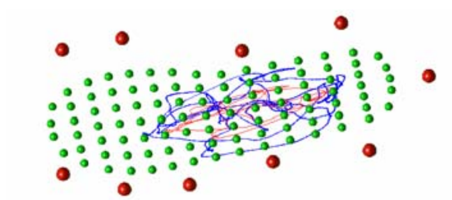

Figure 2. A standing calibration trial was used to establish the location of the sensors (small dots) that optimized agreement between the insole and forceplate measured COP trajectories.

A two stage transformation was used to map the insole sensor locations into the lab reference frame. The first transformation determined the global position of the insole sensors in the calibration trial. Numerical optimization was used to determine a linear transformation from the ground to the insole reference frame that minimized the differences between the insole COP trajectory and the forceplate COP trajectory (Figure 2).

The second stage used piecewise affine transformations to describe the position of the moving insole sensors with respect to the calibration trial. At each frame of a motion trial, a separate affine transformation was used for each sensor. This transformation was obtained from the measured relative motion of the virtual markers with respect to the calibration trial. It was quantified by placing an orthonormal basis in the nearest virtual marker to the sensor, and defining the principal axes of the transformation using the neighboring markers.

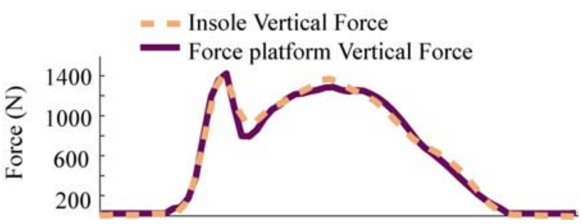

Figure 3. Agreement between net vertical force recorded by the insole and forceplate.

RESULTS

The proposed affine transformation approach generated estimates of the vGRF and COP that were remarkably similar to that measured by the forceplate (Figure 3). Root mean square (RMS) differences in the vGRF were <1% of peak vertical force for walking and <2% of peak vertical force for running. RMS differences in the COP were <5 mm during walking and <9 mm during running (Table 1). The largest errors in the COP trajectory occurred at heel strike.

Table 1: Mean (SD) RMS differences between the forceplate and insole in the vGRF and global position of the COP.

Speed	**vGRF (N)**	**COP (mm)**
Slow Walk	5.3 (4.0)	3.5 (0.5)
Preferred Walk	6.7 (4.4)	4.6 (0.7)
Fast Walk	6.7 (4.7)	4.5 (0.9)
Preferred Run	23.3 (11.2)	8.4 (1.5)
Fast Run	26.8 (12.9)	7.5 (1.9)

DISCUSSION

We have demonstrated a novel approach to tracking the global position of the pressure on the bottom of the feet during human walking and running. There are two important uses of this information in biomechanics. One application is the refinement of foot-floor contact models used to simulate human locomotion. Most current models use an array of discrete visco-elastic units on the sole of the foot (Gilchrist and Winter, 1996). Accurate pressure distribution could be used to both estimate contact model parameters and validate model predictions. A second application is in least squares inverse dynamics (LSID), which uses the kinematics of a whole body model to calculate the missing ground reaction components (Kuo, 1998). Such an approach would be a powerful alternative to the use of fixed forceplates for calculating internal joint torques during human locomotion.

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