Foot strike angle calculation during running based on in-shoe pressure measurements

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Foot strike angle calculation during running based on in-shoe pressure measurements

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Keywords: modeling; forefoot strike; heel strike; mid-foot strike; running

Introduction
The foot strike angle (FSA) is a common biomechanical parameter in the analysis of human running. It can be used for shoe recommendation purposes by classifying runners into foot strike patterns (Zrenner et al., 2018) or for fatigue detection during running (Strohrmann, Harms, Tröster, Hensler, & Müller, 2011). The FSA can accurately be determined in a laboratory setting using motion capture systems. However, those systems do not allow for continuous FSA measurement during natural

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Table 1. Demographics, impact, and spatio-temporal characteristics for the groups of rearfoot strikers.

<table>
<thead>
<tr>
<th></th>
<th>Typical rearfoot (n = 72)</th>
<th>Atypical rearfoot (n = 27)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>35.4 ± 10.3</td>
<td>36.7 ± 7.7</td>
<td>0.537</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.72 ± 0.09</td>
<td>1.75 ± 0.07</td>
<td>0.252</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>68.2 ± 12.6</td>
<td>70.7 ± 9.2</td>
<td>0.357</td>
</tr>
<tr>
<td>Resultant tibial shock (g)</td>
<td>11.7 ± 3.39</td>
<td>17.3 ± 4.6</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Axial tibial shock (g)</td>
<td>8.1 ± 2.5</td>
<td>9.1 ± 3.1</td>
<td>0.040*</td>
</tr>
<tr>
<td>Vertical loading rate (BW/s)</td>
<td>95.9 ± 22.2</td>
<td>110.2 ± 29.2</td>
<td>0.027**</td>
</tr>
<tr>
<td>Speed (m/s)</td>
<td>3.21 ± 0.07</td>
<td>3.22 ± 0.06</td>
<td>0.785</td>
</tr>
<tr>
<td>Contact time (ms)</td>
<td>270.4 ± 20.5</td>
<td>254.1 ± 18.6</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Step frequency (Hz)</td>
<td>2.80 ± 0.14</td>
<td>2.78 ± 0.15</td>
<td>0.517</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± SD.
*One-tailed test.
**Significant difference.

References
in-field running. Therefore, various approaches for in-field measurements have been presented in literature. Inertial measurement units (IMUs) placed inside or outside the shoe currently represent the most promising tool for FSA measurements during in-field running. However, IMUs require sophisticated algorithms (e.g. sensor fusion, drift correction, auto calibration) to accurately determine the FSA.

**Purpose of the study**

To present a simple method for FSA calculation based on in-shoe pressure measurements and to evaluate the effect of different modelling techniques on calculated FSA accuracy by comparison with the ground truth (GT) FSA.

**Methods**

Twenty recreational male runners participated in this study. After running in their natural strike pattern, participants were instructed to imitate five different strike patterns (extreme fore-foot, fore-foot, mid-foot, rear-foot and extreme rear-foot) during over ground running in the lab. Twenty steps were recorded in every condition.

Kinematics (left foot) were recorded (Qualisys, 100 Hz) to determine the GT FSA at initial contact. Pressure measurements were conducted using a wireless two sensor (fore & rear-foot) insole (Loadsol – Novel, 100 Hz). 16 force and time related variables were derived from the two pressure signals.

Three different modelling techniques were used for FSA calculation: (i) single item regression analysis (SR, best predictive item in terms of highest average $R^2$), (ii) multiple regression analysis (MR) and (iii) artificial neural network (ANN). To avoid overfitting, ANN was trained using a five-fold cross-validation. Data from participants 1–10 were used for modelling (model set), while data from participants 11–20 were used for validation (validation set).

Accuracy evaluation was conducted using error (= difference) and mean absolute error (MAE: across the 20 trials within each strike pattern condition for each

![Figure 1](image-url)

**Table 1.** Effect of modelling techniques on calculated FSA accuracy (MAE ± SD, $\mu$).

<table>
<thead>
<tr>
<th></th>
<th>Model set</th>
<th>Validation set</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR</td>
<td>3.5 (2.9)</td>
<td>4.8 (3.2)</td>
</tr>
<tr>
<td>MR</td>
<td>2.9 (1.6)</td>
<td>4.2 (2.5)</td>
</tr>
<tr>
<td>ANN</td>
<td>2.9 (1.7)</td>
<td>4.2 (2.7)</td>
</tr>
<tr>
<td>$p$; $\eta^2$</td>
<td>&lt;0.001; 0.178</td>
<td>0.015; 0.089</td>
</tr>
</tbody>
</table>

+$-$ Different from SR, MR and ANN, respectively.

Figure 1. FSA accuracy evaluation of the three modelling techniques (SR, MR, ANN) using Bland-Altman. Average accuracy values are indicated by A (mean ± 95%CI). Grey-scaled dots indicate the instructed foot strike patterns.
We presented a simple method, which is capable of accurately detecting FSA during running. The calculated FSA accuracy was shown to be sensitive to the modelling technique. Comparing modelling and validation results (Figure 1) suggests that more participants are required for modelling to increase accuracy when using this approach for FSA calculation.

Disclosure statement
No potential conflict of interest was reported by the authors.

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References

The effect of strike pattern on the cushioning capacity of technical midsole systems
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Abstracts
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Introduction
Several studies have indicated a functional relationship between footwear and strike patterns in runners (Kasmer, Liu, Roberts, & Valadao, 2016). The mechanisms that dictate these kinematic adaptations are widely accepted to rely on the way impacts are sensed and transferred through the runners’ musculoskeletal system (Lieberman et al., 2010). As a result, multiple...