A COMPARISON OF FOUR METHODS OF CALCULATING VERTICAL STIFFNESS IN DISTANCE RUNNING

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INTRODUCTION

Vertical stiffness is a useful method for characterizing distance running. It has been correlated with stride frequency, surface, speed, and aerobic demand (Arampatzis, 1999, Heise, 1998, Farley, 1996, Kerdok, 2002, McMahon, 1990, Dalleau, 1998). However, there are limitations to the traditional method of calculating stiffness. The heel strike and initial slope compared with the final slope are poorly matched when reproducing force based upon the calculated stiffness and initial conditions (Figure 1).

Another approach was recently introduced measuring a stiffness that begins relatively high, and then drops to a lower stiffness around the heel strike (Hunter, 2002). This method matches reproduced force very well (Figure 2).

This study compares the benefits and drawbacks to three different constant stiffness methods and the variable stiffness method.

METHODS

Four methods of calculating vertical stiffness were compared by their correlations with measured versus modeled vertical ground reaction forces

Traditional: The traditional method of calculating stiffness divides the maximum vertical ground reaction force by the change in vertical position of the center of mass from foot contact to the maximum displacement.

Constant low: This method differs from the traditional method by dividing by the maximum vertical displacement of the
center of mass from the lowest point to takeoff.  
**Constant best fit:** This is a constant stiffness method using a stiffness that provides the best fit between measured and modeled vertical ground reaction forces.  
**Variable:** This method uses a best fit model with an initial high stiffness that drops to a lower value around the heel strike. The drop begins at the peak force of heel strike and ends at the valley between heel strike and the active peak.

**RESULTS AND DISCUSSION**

All methods were significantly different from each other using an adjusted significance level of 0.0083 for multiple comparisons (Table 1). While the differences between most methods were practically non-significant, the variable stiffness method appeared functionally significant. It is clear visually and statistically that the variable stiffness method provides a much better fit than any other method. 

The variable stiffness method may be the best fit for the following reasoning. The body reacts very stiff to the ground at initial contact. As the foot becomes flat to the ground, the center of pressure progresses forward, resulting in a lengthening of the leg spring. Since the leg spring is slightly increasing, the stiffness will decrease during this time. Once the foot is flat on the ground, the ankle becomes more involved in the stance. With an additional joint becoming a major part of the spring, the overall stiffness may decrease.

While two variables are required to use the vertical stiffness model (initial and final stiffnesses), there may be cases where only the initial or final stiffness may be of importance in the model being considered.

**SUMMARY**

The variable stiffness method for calculating vertical stiffness provides the best fit for modeling vertical ground reaction forces. However, there are two variables required to use this method.

**REFERENCES**


**Table 1:** Correlations between measured and modeled vertical ground reaction forces using four approaches to calculating stiffness (mean± SD) (all methods were significantly different from all others, p<0.0083).

<table>
<thead>
<tr>
<th>Stiffness method Correlation</th>
<th>Method 1</th>
<th>Method 2</th>
<th>Method 3</th>
<th>Method 4</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0.948±0.026</td>
<td>0.940±0.028</td>
<td>0.960±0.020</td>
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