AMBULATORY MEASUREMENTS REQUIRE DEFORMABLE FOOT MODELS

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INTRODUCTION

In the more or less standard approach in movement analysis, body movement is measured in a laboratory equipped with a video system and build-in force plates. With optical markers the movement is reconstructed as if these were fixed positions on a linked system of rigid bodies. The measured ground reaction forces provide the remaining input for an inverse analysis.

A lot of applications require movement analysis outside the laboratory setting. The development of ambulatory movement measurement systems is therefore a research topic in several groups. The ambulatory system of the FreeMotion consortium consists of a set of inertial sensors to capture body accelerations and angular velocities combined with an instrumented shoe to measure ground reaction forces (figure 1) [1].

Besides the many advantages of the ambulatory system, an important disadvantage is the lack of an absolute reference position. In a position based measurement system, one may consider the foot as a rigid segment since this does not lead to errors in the calculated joint torques and powers. In an ambulatory system, however, the absolute (joint) positions are constructed from the floor upwards. In this case the foot cannot be considered rigid anymore.

The purpose of this study is to demonstrate the effects of the rigid foot assumption and to define the properties of a suitable foot model for ambulatory systems.

Figure 1. *Instrumented shoe with two force transducers and inertial sensors (in orange attached to the transducers).*

METHODS

The gait of a healthy subject was captured in a standard video-based system and simultaneously with the FreeMotion ambulatory system. In both situations the data was analysed by calculating the ankle torques and powers. A difference between both methods is that in the video-based system a standard set of markers is used to estimate the foot orientation, whereas in the ambulatory system also the orientation of the forefoot with respect to the hind foot is taken into account (figure 1). As a result, the first method implicitly assumes the foot as rigid, any deformation that might accur is not directly visible and will result in a deviation from the real ankle angle.

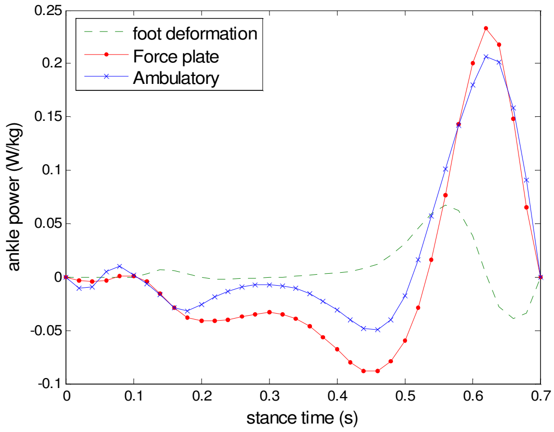

Figure 2. *Comparison of ankle powers during the stance phase of walking.*

RESULTS AND DISCUSSION

Ground reaction forces and ankle torques differed less than 3% between both methods. The differences in the ankle power, however, were about 12% of the maximum value on average (figure 2). This indicates that foot deformation is important but is obscured in the ankle angle data for the video-based method. Also, the calculated ankle power must then be the combined result of true ankle power and foot deformation. This is confirmed by the ambulatory data, where the difference in ankle power with the video data is for a large part explained by the power to deform the forefoot with respect to the hind foot (figure 2).

These results show that in order to reconstruct joint positions accurately (and to perform an accurate movement analysis) with an ambulatory system, a deformable foot segment must be included. In most applications it is not important how the foot deforms, as long as the effects on the rest of the body are known. The main demand for the foot model is then that it should accurately predict the ankle position (with respect to the centre of pressure) as a function of the lower leg orientation and external loading. Furthermore, it would be advantageous if the deformation would be entirely passive, i.e. not requiring active muscle control. First experiments with a simple, two-segmental foot model show satisfactory behavior when applied to gait (not shown here).

REFERENCE

1. Schepers H.M. et al. (2007), IEEE trans Biomed Eng (in press).

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